US009279942B2

(12) United States Patent
Li et al.

(10) Patent No.: **US 9,279,942 B2**
(45) Date of Patent: **Mar. 8, 2016**

(54) **FERRULE FOR OPTICAL FIBER CONNECTOR HAVING A COMPLIANT STRUCTURE FOR CLAMPING ALIGNMENT PINS**

(71) Applicant: **NANOPRECISION PRODUCTS, INC.**, El Segundo, CA (US)

(72) Inventors: **Shuhe Li**, Pasadena, CA (US); **Robert Ryan Vallance**, Newbury Park, CA (US); **Michael K. Barnoski**, Pacific Palisades, CA (US); **Gregory L. Klotz**, La Verne, CA (US)

(73) Assignee: **NANOPRECISION PRODUCTS, INC.**, El Segundo, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **13/650,119**

(22) Filed: **Oct. 11, 2012**

(65) **Prior Publication Data**

US 2013/0266268 A1 Oct. 10, 2013

Related U.S. Application Data

(60) Provisional application No. 61/620,945, filed on Apr. 5, 2012.

(51) **Int. Cl.**
G02B 6/36 (2006.01)
G02B 6/38 (2006.01)

(52) **U.S. Cl.**
CPC ***G02B 6/36*** (2013.01); ***G02B 6/3839*** (2013.01); ***G02B 6/3882*** (2013.01); ***G02B 6/3885*** (2013.01)

(58) **Field of Classification Search**
CPC .. G02B 6/3882; G02B 6/4471; G02B 6/3636; G02B 6/364; G02B 6/381; G02B 6/3839
USPC 385/59, 65, 64, 71, 83, 81
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,830,456 A * 5/1989 Kakii et al. 385/75
4,973,127 A 11/1990 Cannon, Jr. et al.

(Continued)

FOREIGN PATENT DOCUMENTS

EP	0271721	6/1988
EP	0800100	10/1997
JP	06-34845	2/1994

OTHER PUBLICATIONS

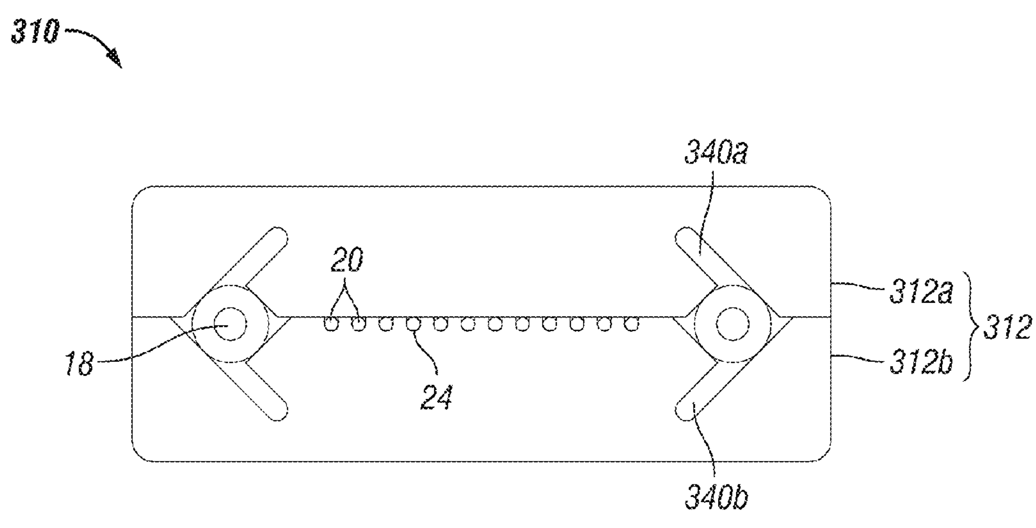
International Search Report of Counterpart PCT International Application No. PCT/US2012/059835.

Primary Examiner — Ellen Kim
(74) *Attorney, Agent, or Firm* — Liu & Liu

(57) **ABSTRACT**

A compliant structure clamps the alignment pins to accurately and precisely locate the alignment pins. The compliant structure supports the alignment pins with no clearance. The compliant structure is defined by at least a flexure in the form of a cantilevered structure extending at a side of the ferrule. The cantilevered structure, with or without a complementary support structure, defines a space in which an alignment pin can be supported. The flexure may be defined by one or more slots provided on the body of the ferrule to facilitate bending of the extended cantilevered structure. In another embodiment, the ferrule comprises a ferrule insert having grooves for supporting optical fibers, and a ferrule frame that supports the ferrule insert and alignment pins. The compliant structure is provided on the frame. In a further embodiment, the ferrule insert is provided with optical fiber grooves at its perimeter.

20 Claims, 15 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

5,037,179	A *	8/1991	Bortolin et al.	385/54
5,044,711	A *	9/1991	Saito	385/65
5,379,361	A *	1/1995	Maekawa et al.	385/65
5,416,868	A *	5/1995	Kakii et al.	385/80
5,664,039	A *	9/1997	Grinderslev et al.	385/65
6,474,877	B1 *	11/2002	Shahid	385/65
6,817,777	B1 *	11/2004	Grabbe	385/59
2002/0150349	A1 *	10/2002	Shahid	385/65
2003/0091297	A1 *	5/2003	Hung et al.	385/83
2004/0152354	A1	8/2004	Luther et al.	

* cited by examiner

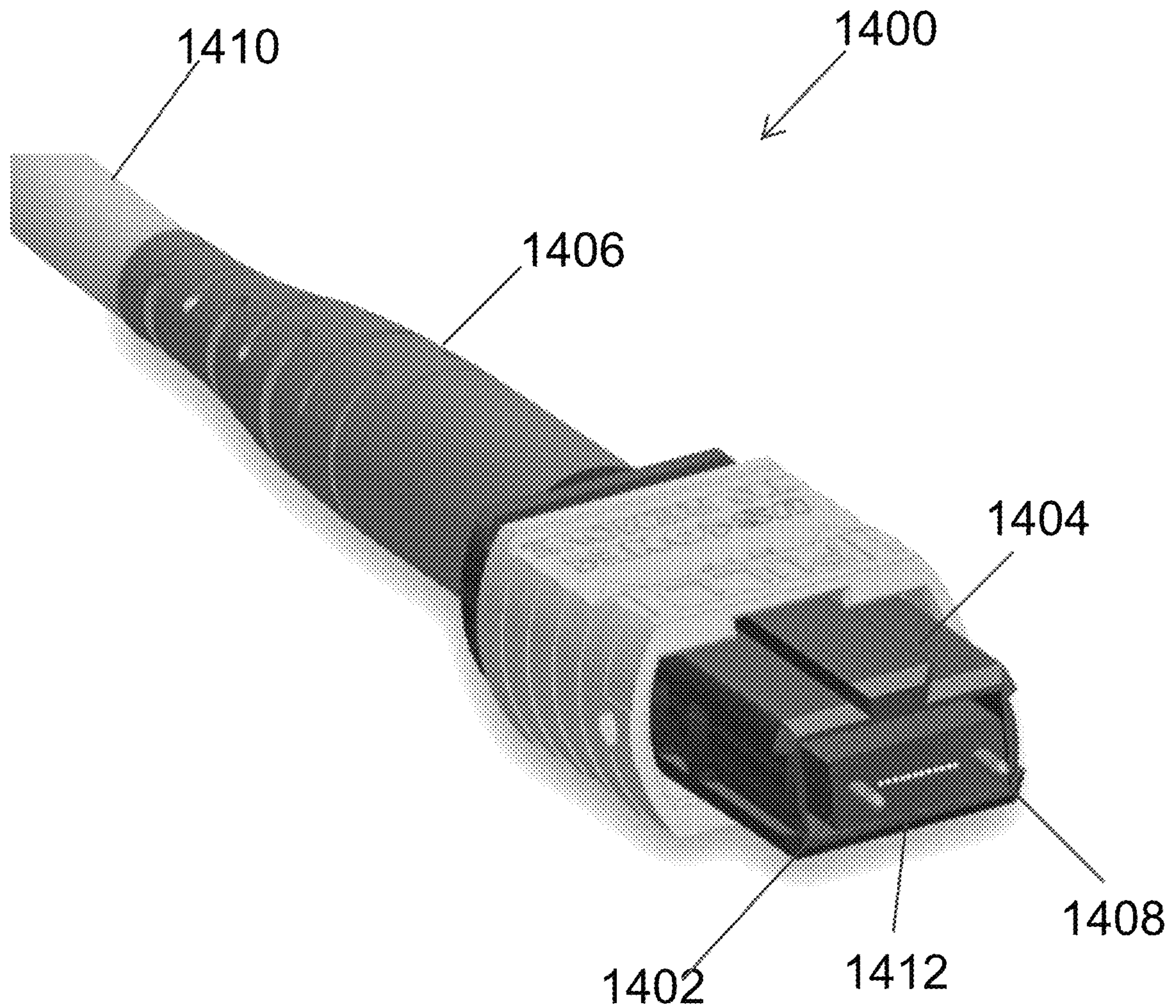


FIG. 1

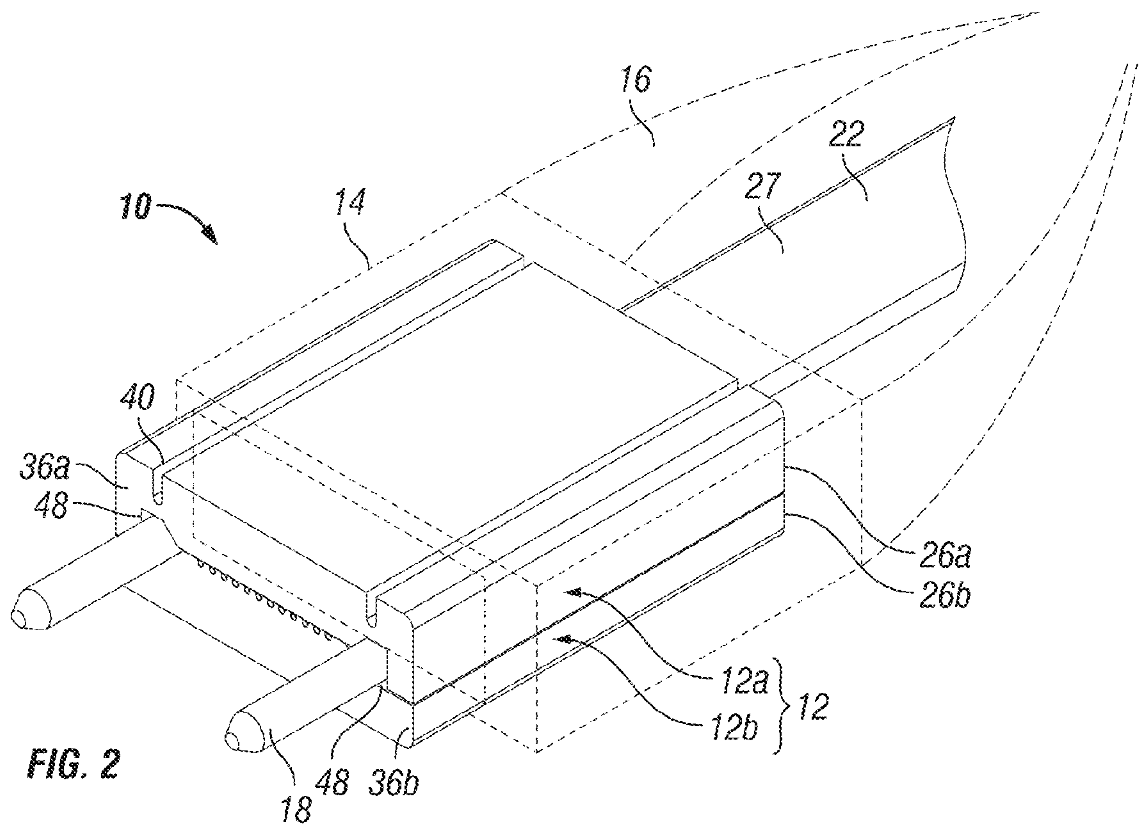


FIG. 2

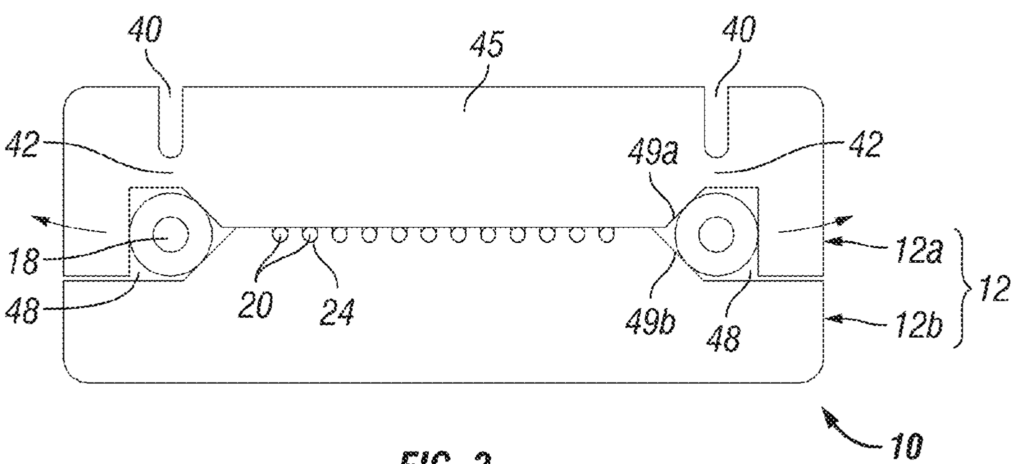


FIG. 3

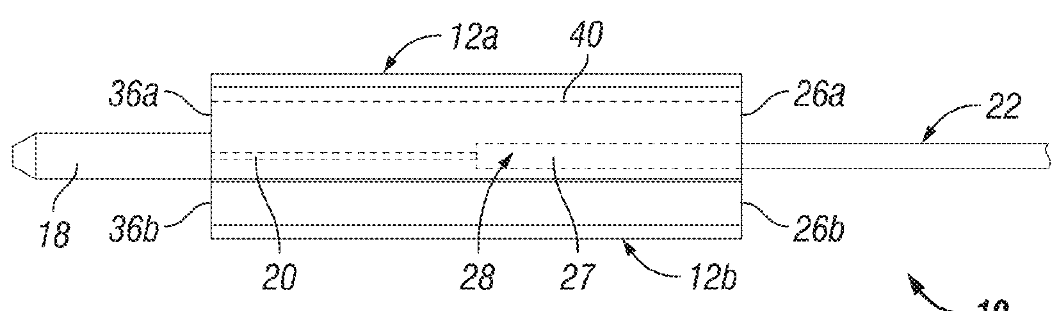


FIG. 4

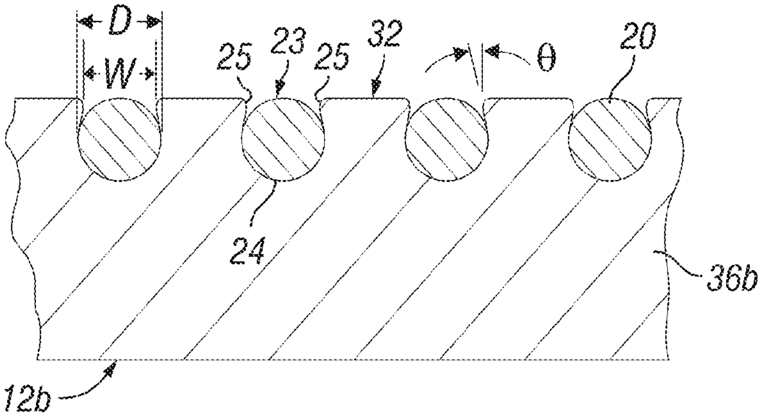


FIG. 5

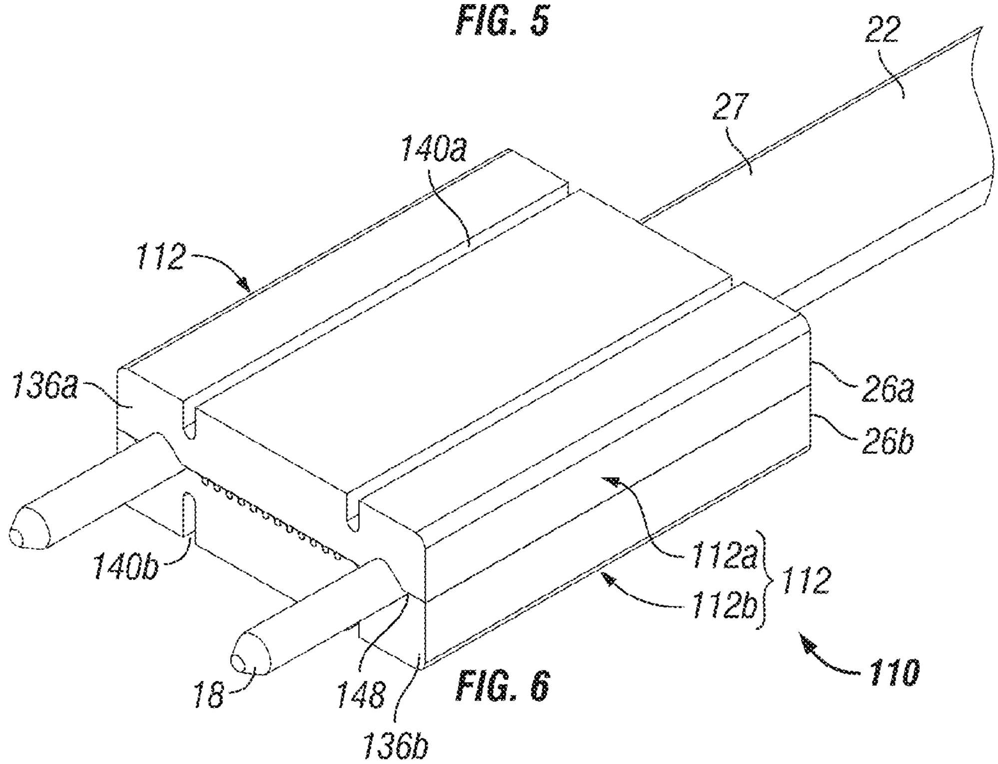


FIG. 6

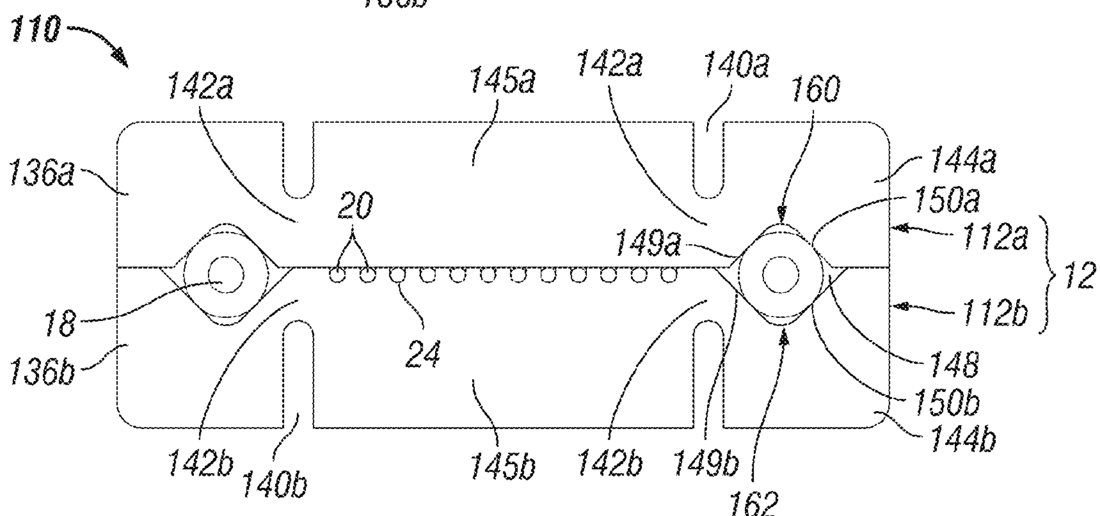


FIG. 7

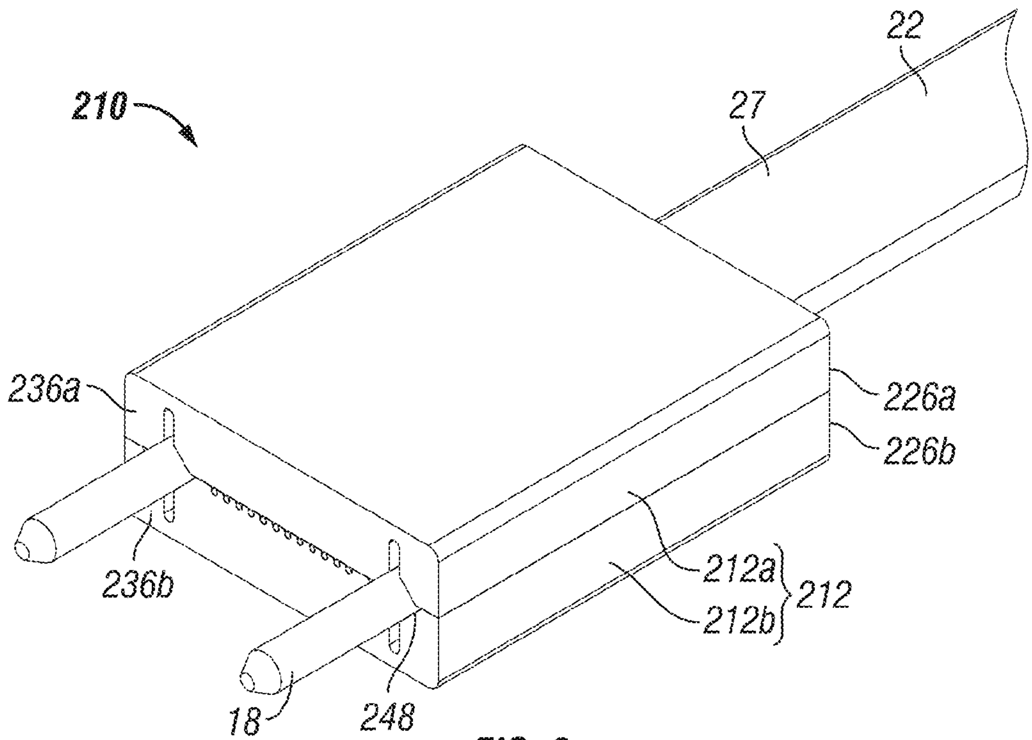

210
22
27
236a
226a
226b
236b
212a
212
212b
18
248

FIG. 8

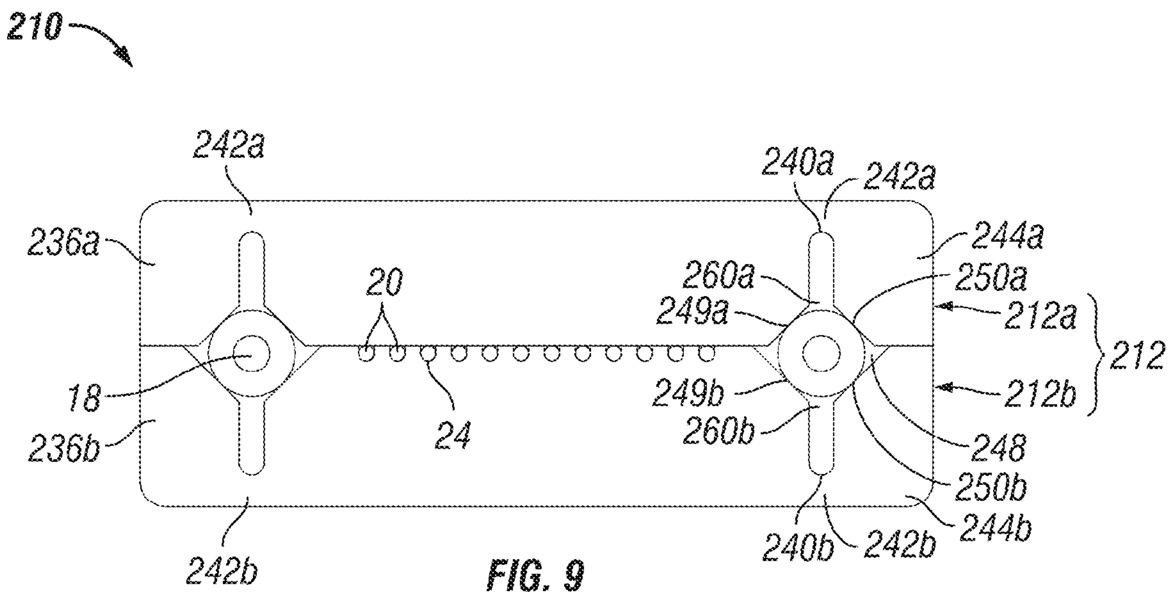

210
242a
240a
242a
236a
244a
260a
250a
20
249a
212a
212
18
249b
212b
260b
24
248
236b
250b
240b
242b
244b
242b

FIG. 9

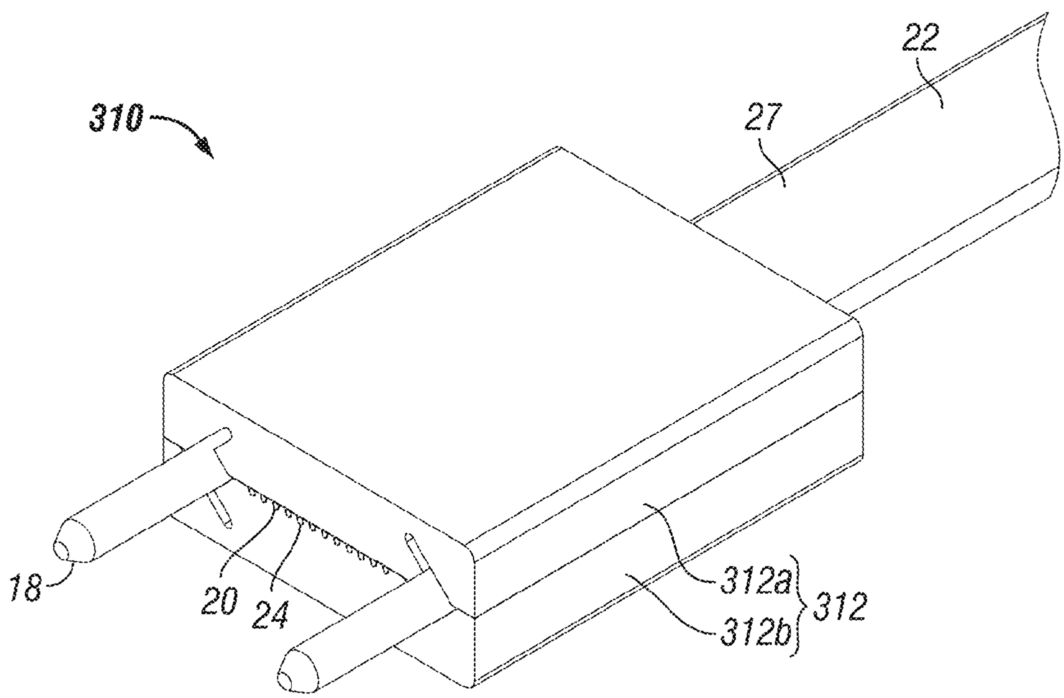

310
22
27
18
20
24
312a
312b
312

FIG. 10

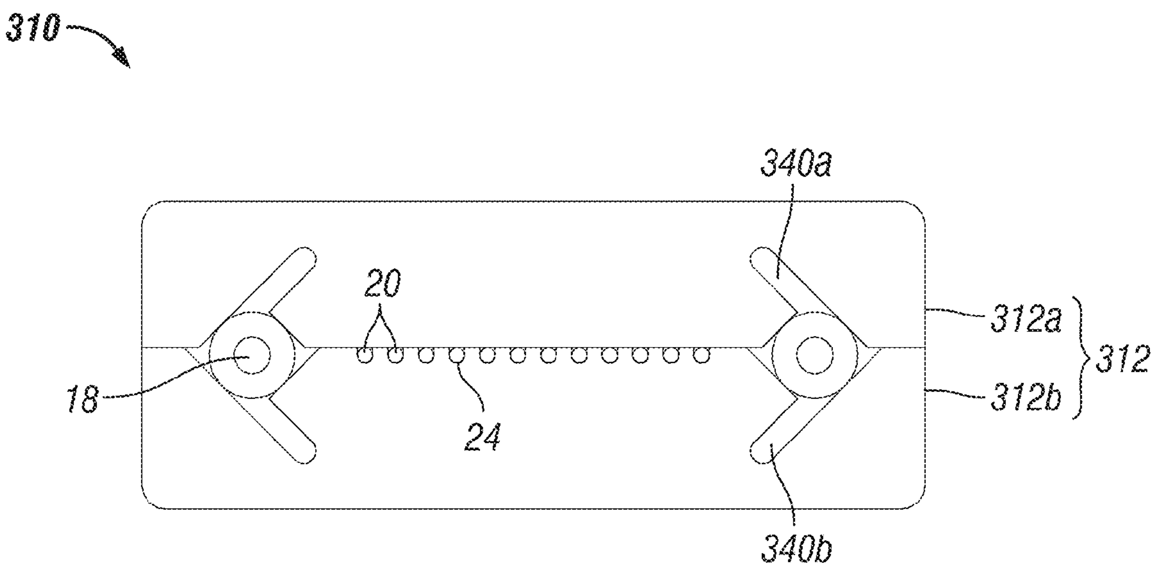

310
340a
20
312a
312
18
24
312b
340b

FIG. 11

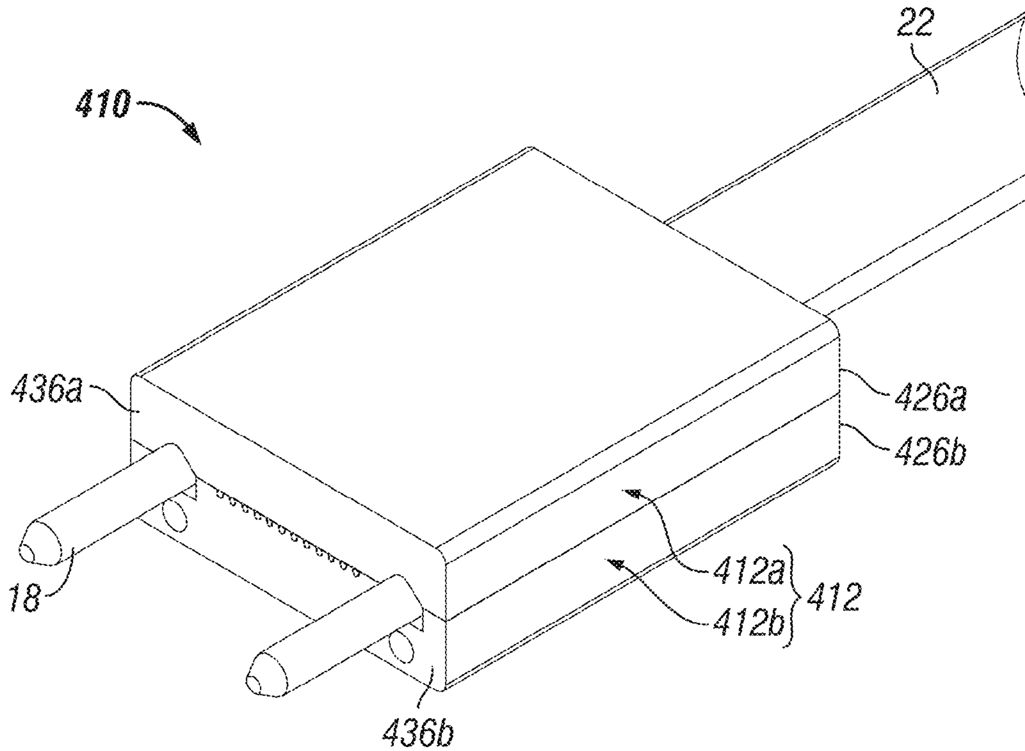

22
410
436a
426a
426b
18
412a
412
412b
436b

FIG. 12

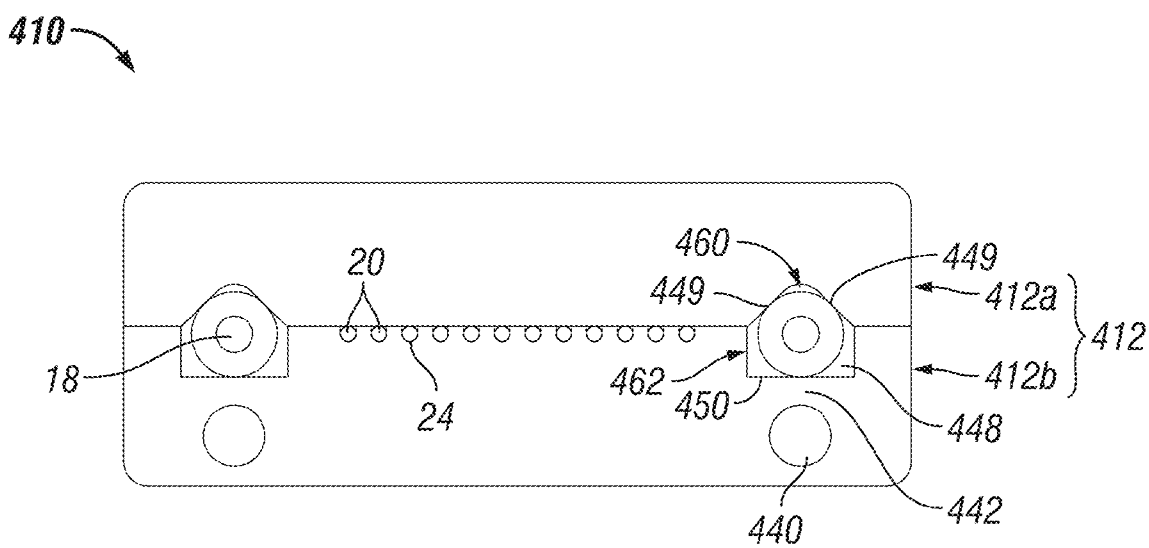

410
460
449
20
449
412a
412
18
462
412b
450
24
448
442
440

FIG. 13

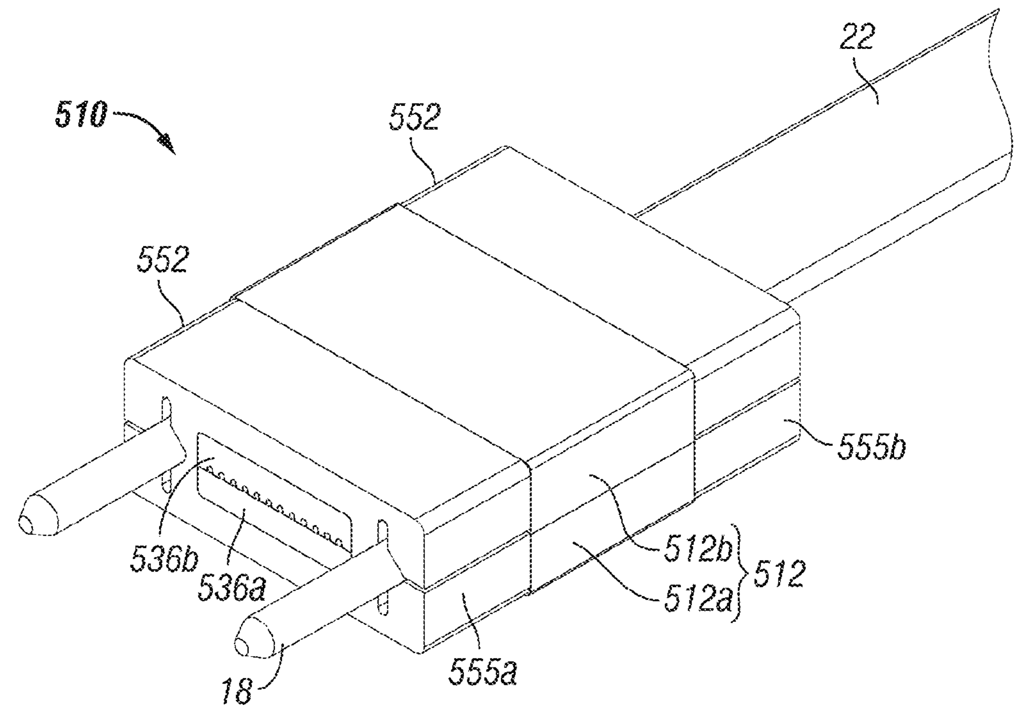


FIG. 14

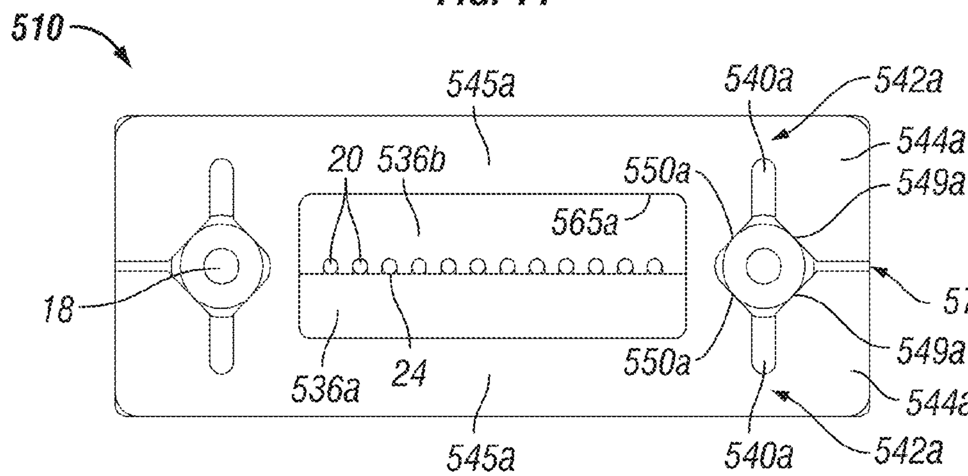


FIG. 15

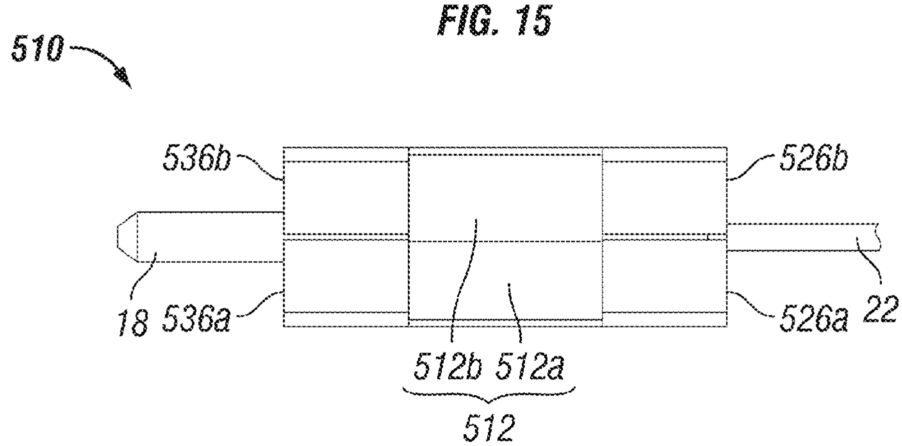


FIG. 16

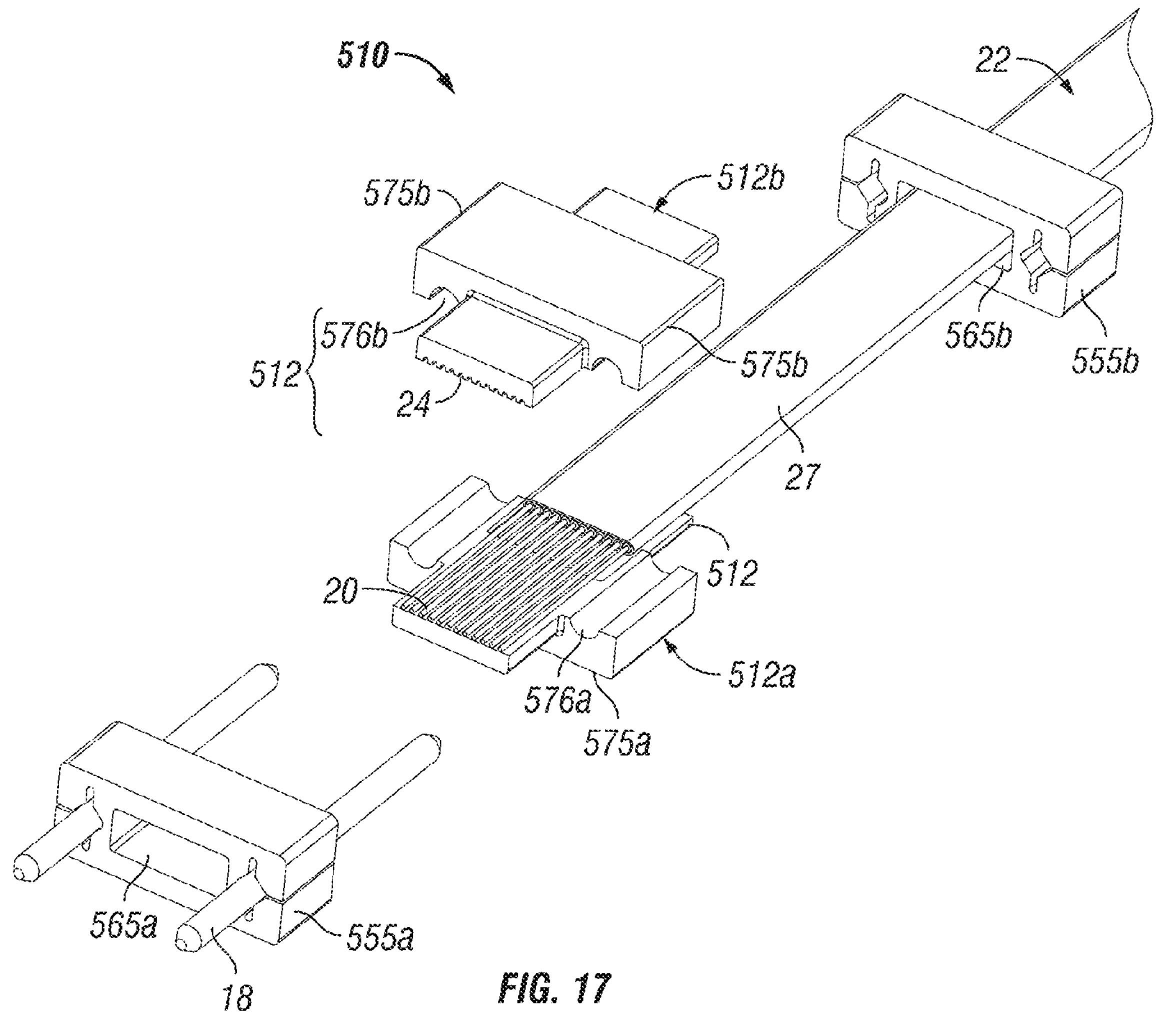

510
22
575b
512b
576b
512
575b
565b
555b
24
27
20
512
512a
576a
575a
565a
555a
18

FIG. 17

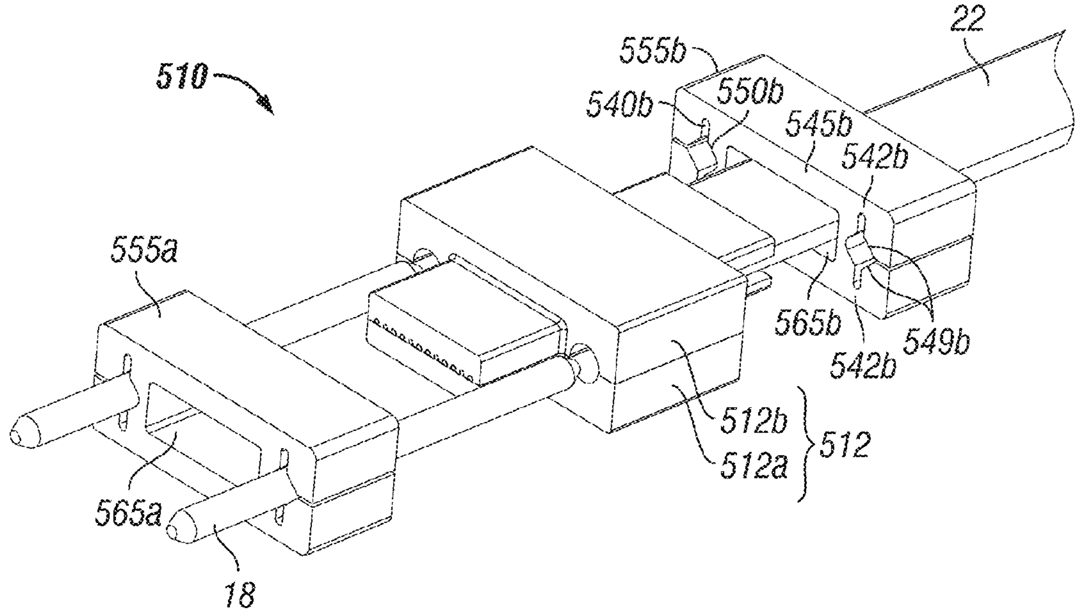
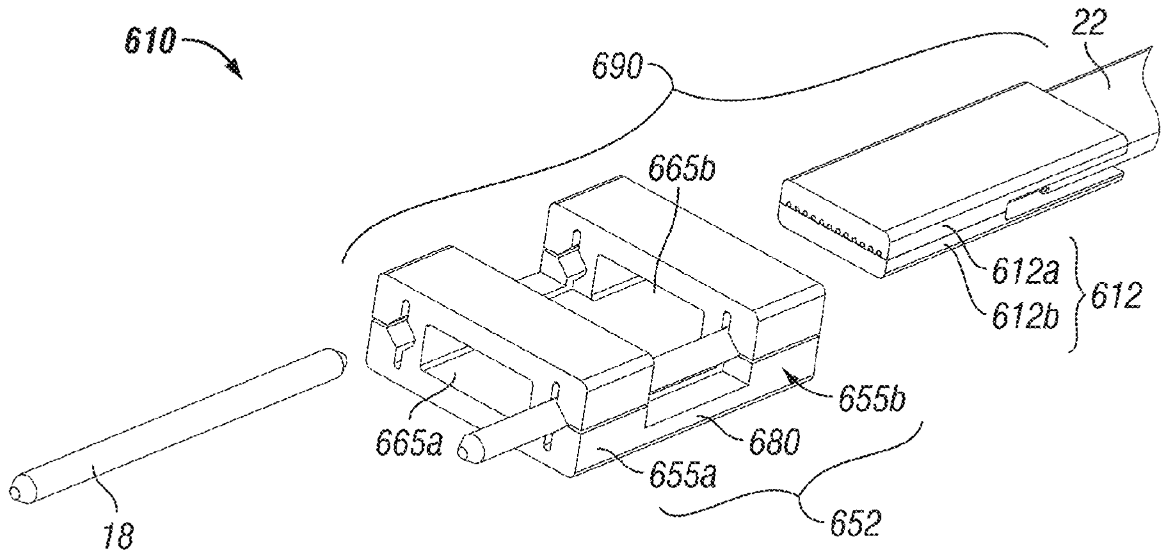
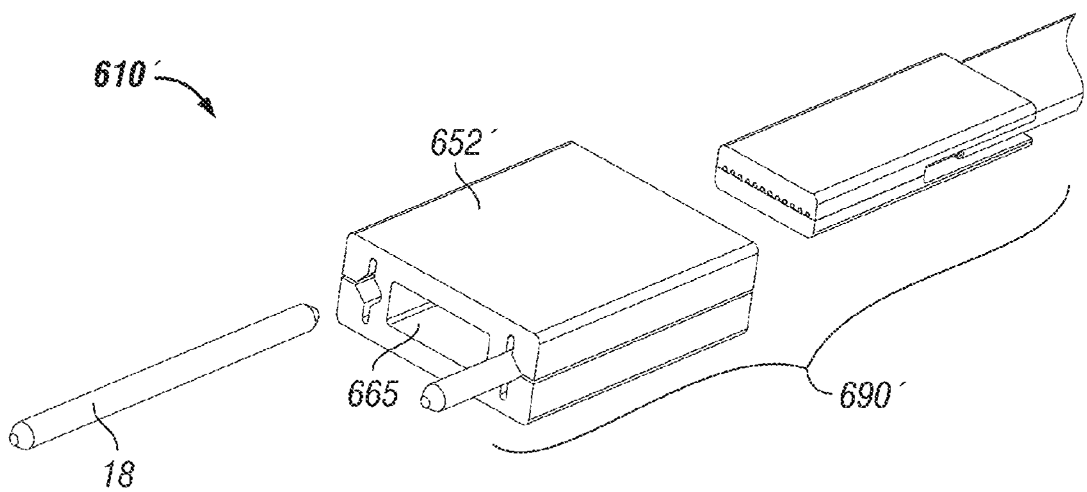

510
555b
22
540b
550b
545b
542b
555a
565b
542b
549b
512b
512a
512
565a
18

FIG. 18



610
690
22
665b
612a
612b
612
655b
665a
680
655a
652
18

FIG. 19



610´
652´
665
690´
18

FIG. 20

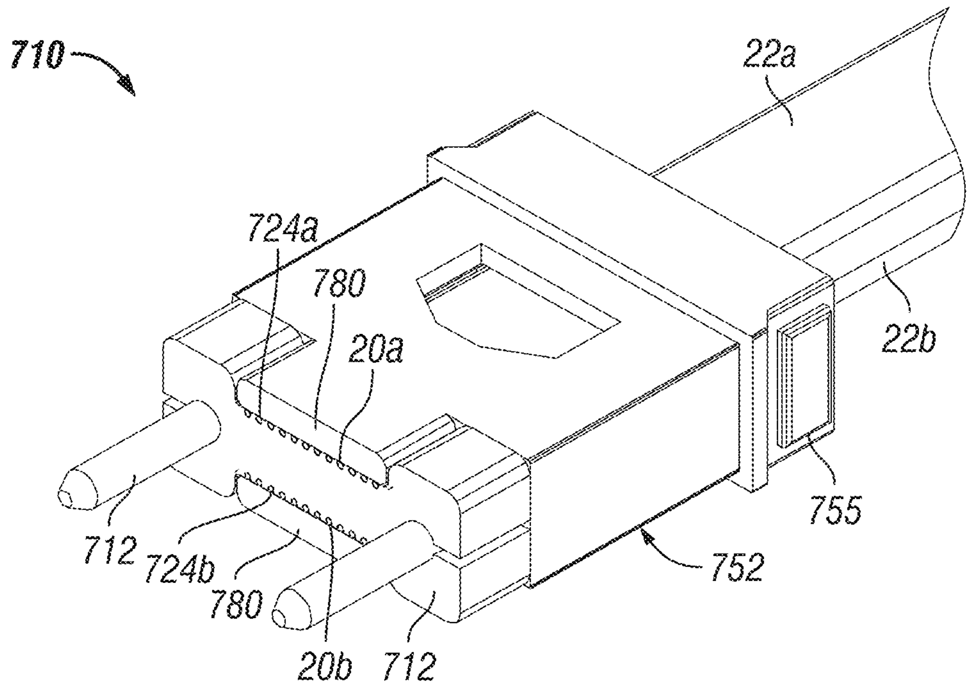

710
22a
724a
780
20a
22b
755
712
724b
780
752
20b
712

FIG. 21

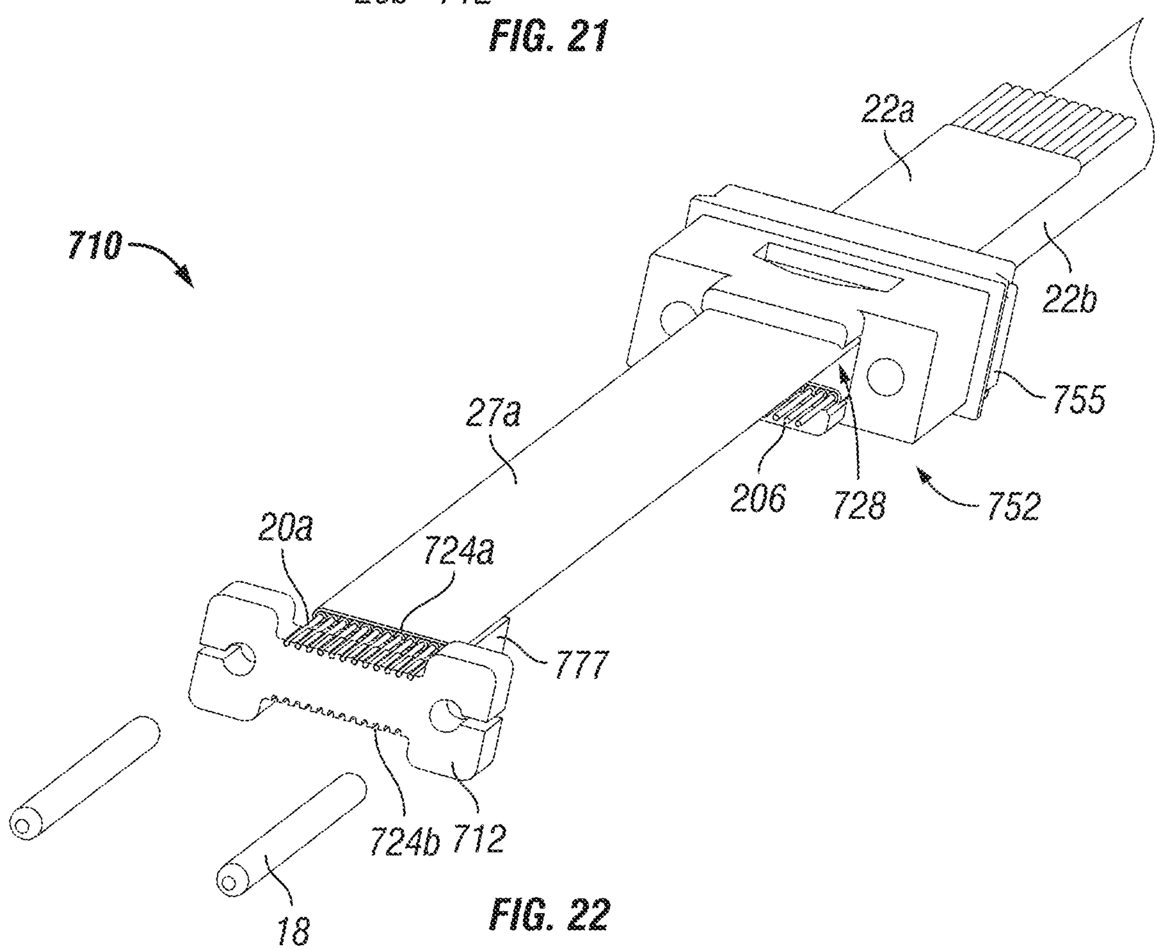

22a
710
22b
755
27a
206
728
752
20a
724a
777
724b
712
18

FIG. 22

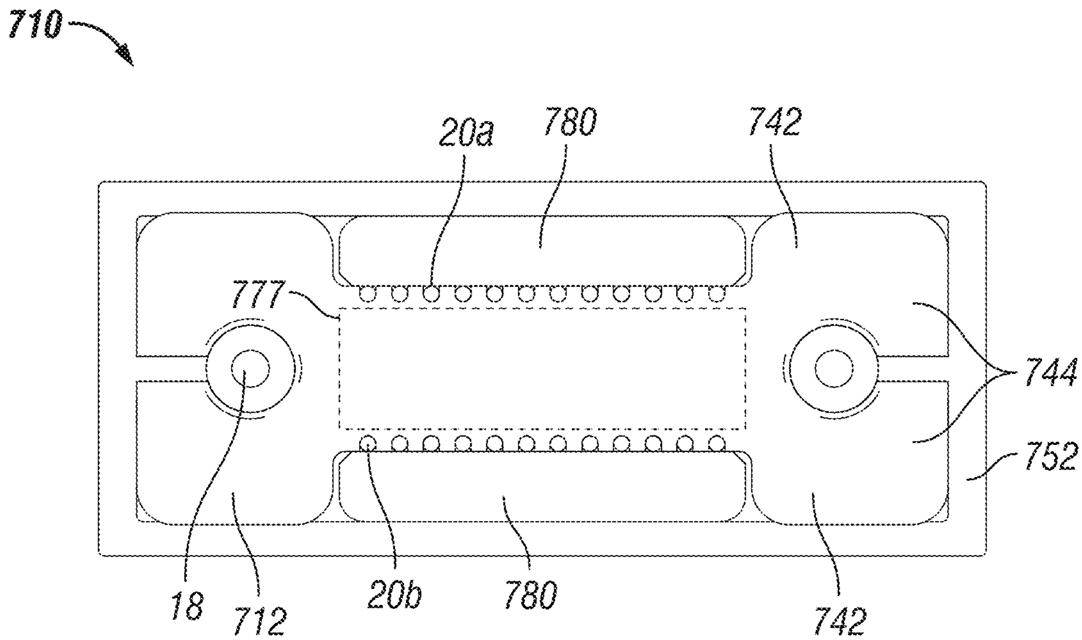

710
20a
780
742
777
744
752
18
712
20b
780
742

FIG. 23

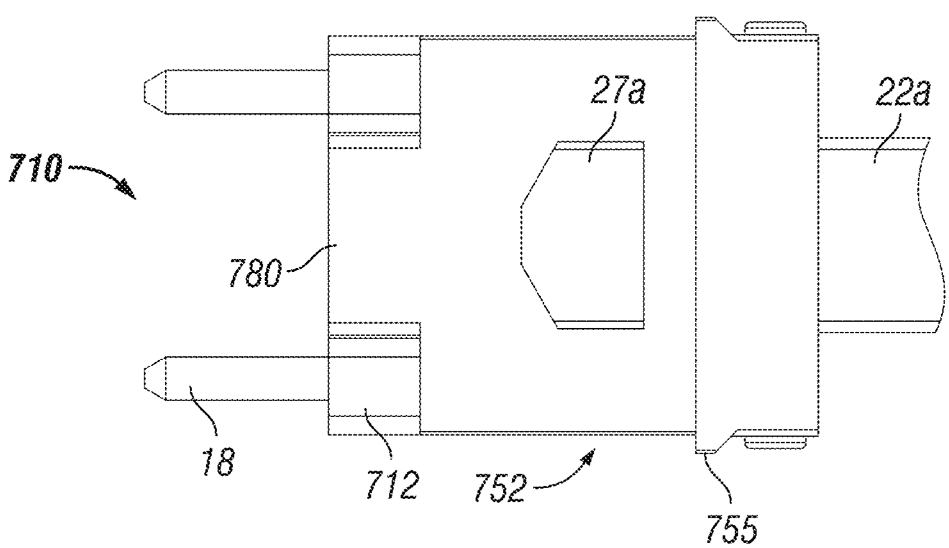

27a
22a
710
780
18
712
752
755

FIG. 24

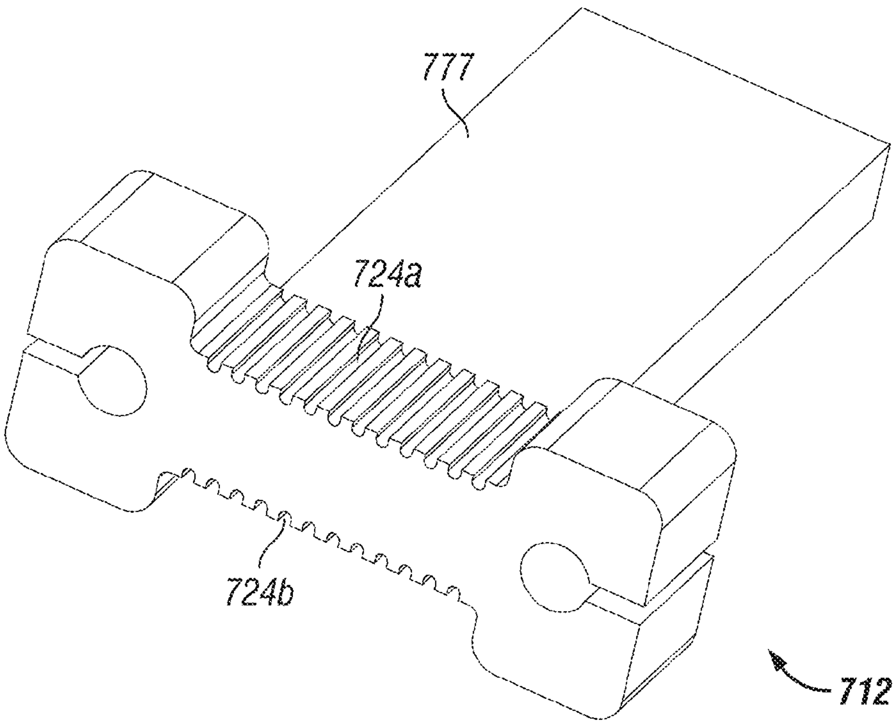


FIG. 25

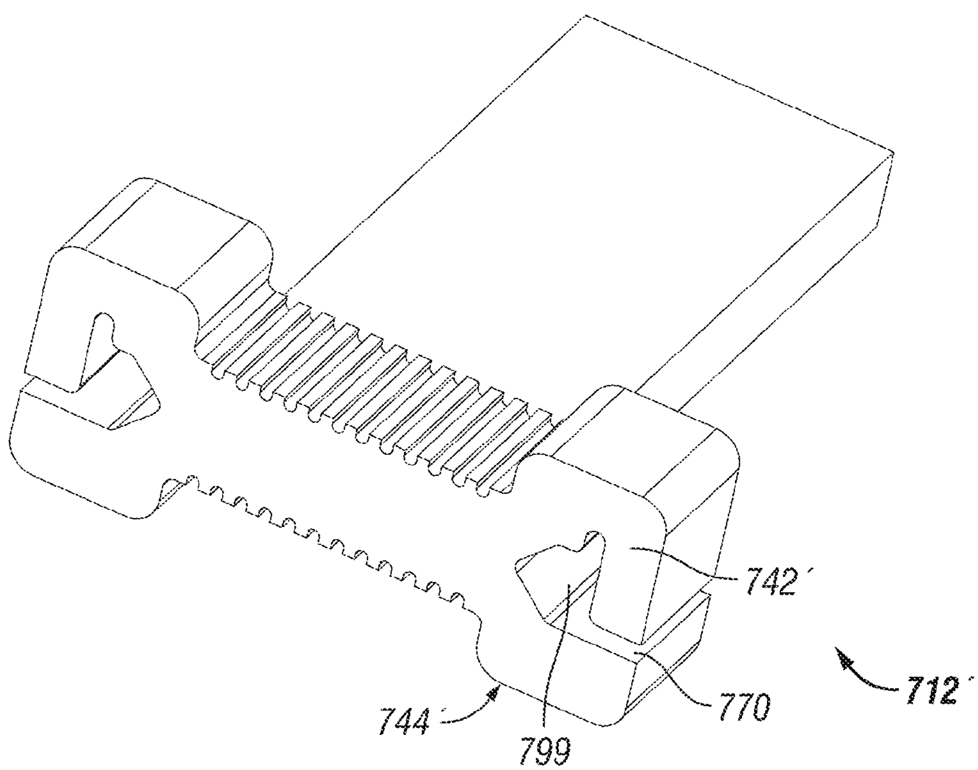


FIG. 26

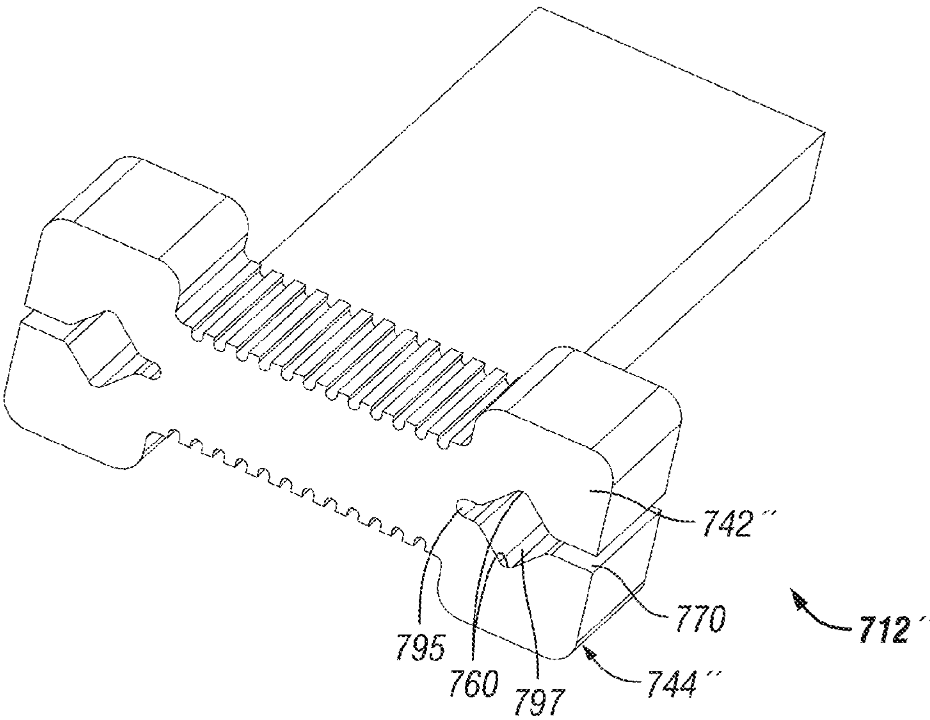


FIG. 27

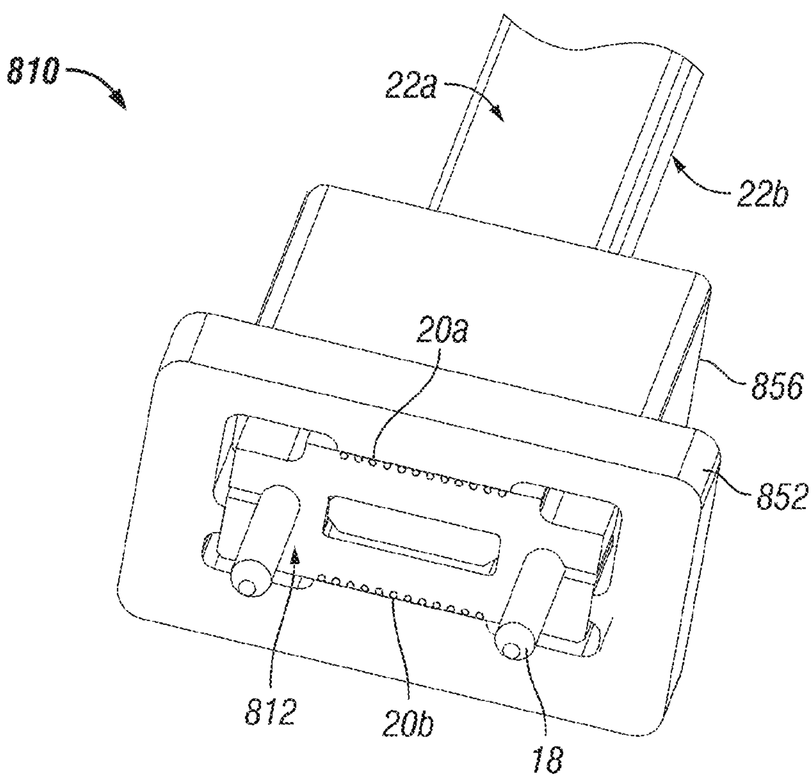


FIG. 28

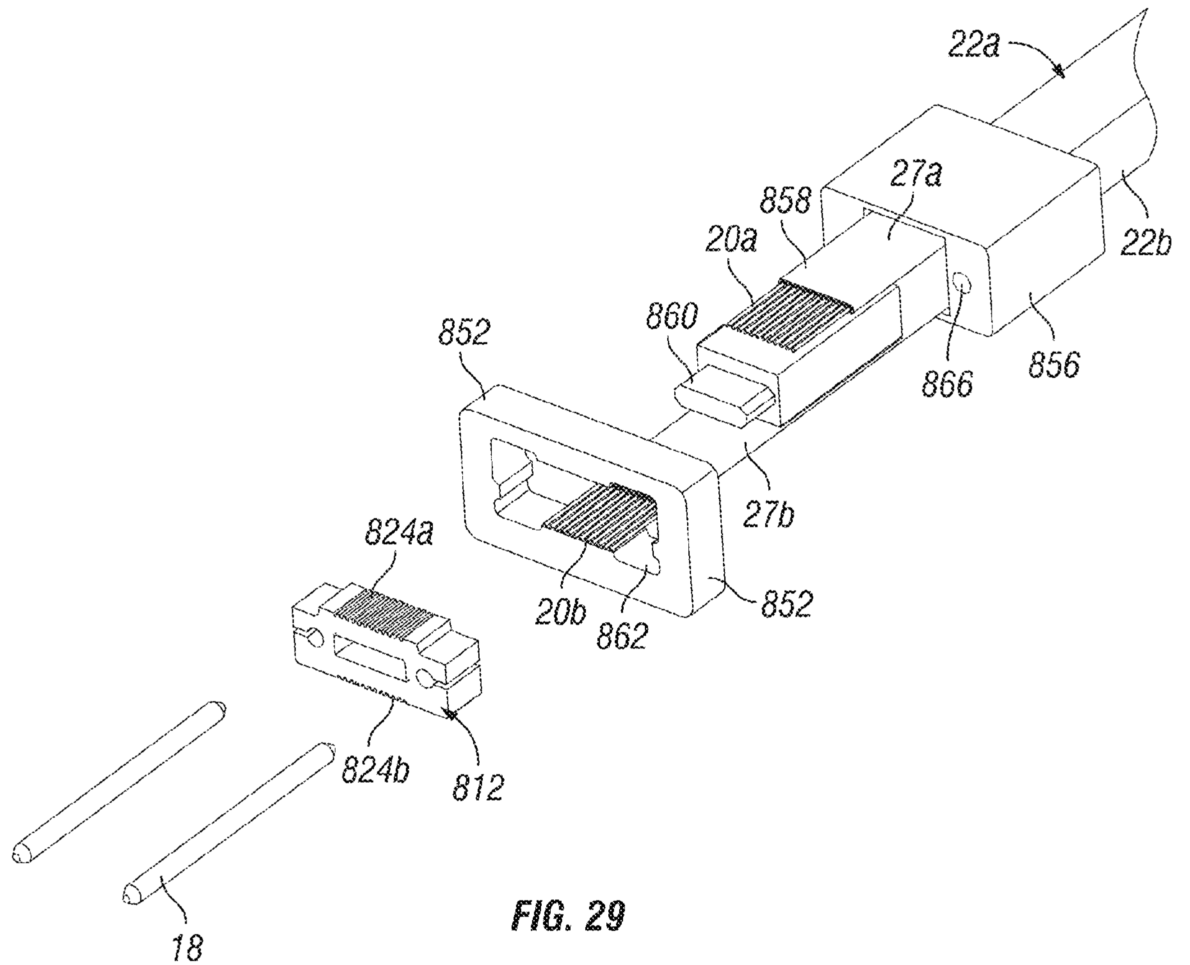

22a
27a
858
22b
20a
860
852
866
856
27b
824a
852
20b
862
824b
812
18

FIG. 29

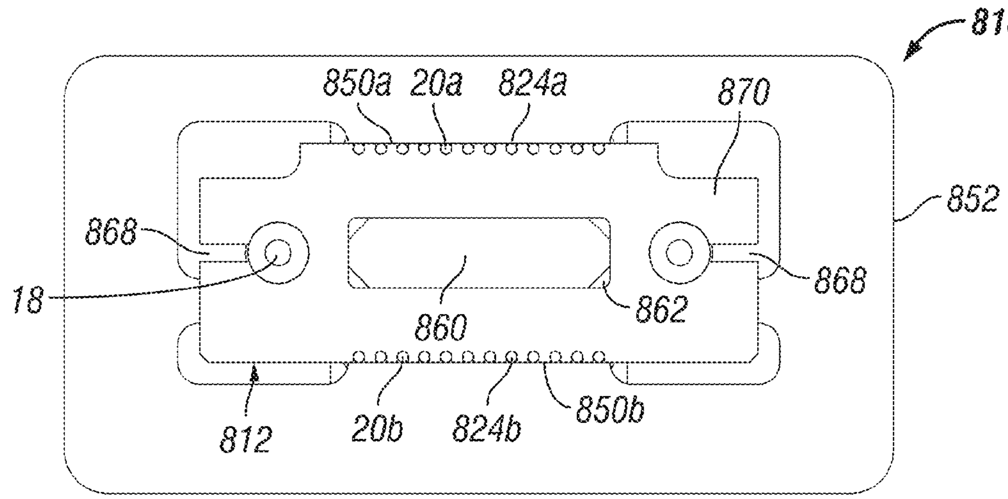


FIG. 30

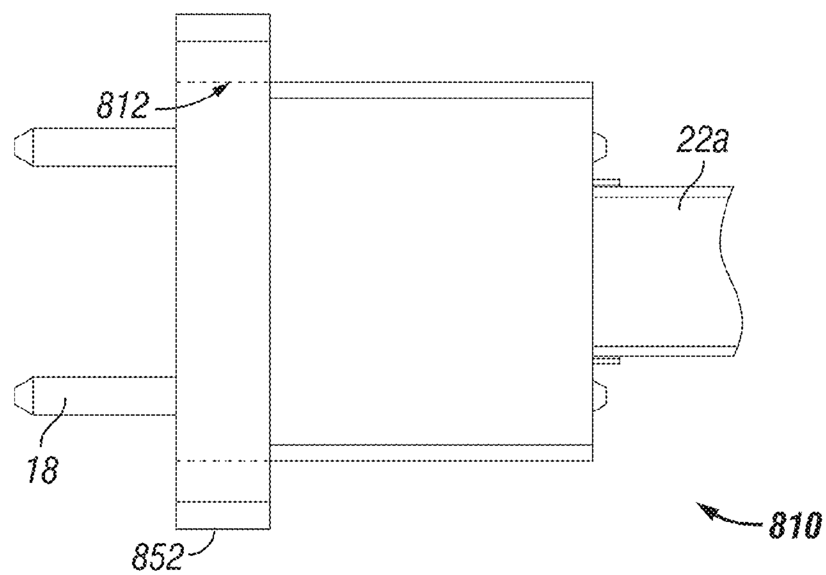


FIG. 31

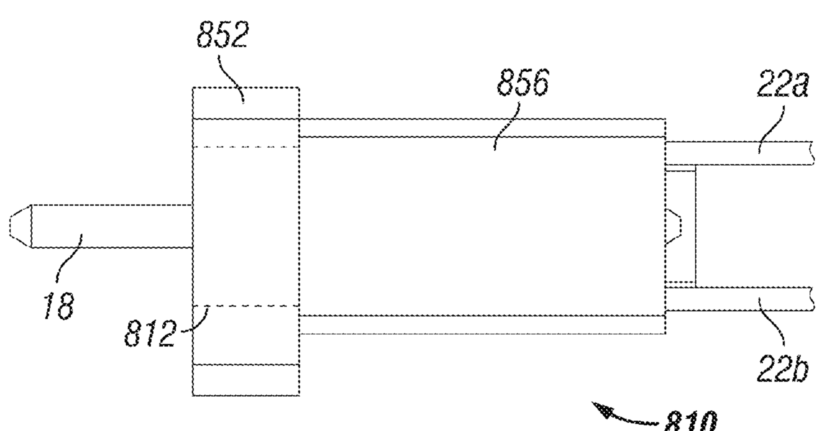


FIG. 32

FERRULE FOR OPTICAL FIBER CONNECTOR HAVING A COMPLIANT STRUCTURE FOR CLAMPING ALIGNMENT PINS

PRIORITY CLAIM

This application claims the priority of U.S. Provisional Patent Application No. 61/620,945 filed on Apr. 5, 2012, which is fully incorporated by reference as if fully set forth herein. All publications noted below are fully incorporated by reference as if fully set forth herein.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to optical fiber connectors, in particular ferrules in optical fiber connectors.

2. Description of Related Art

There are many advantages of transmitting light signal via optical fiber waveguides and the use thereof is diverse. Single or multiple fiber waveguides may be used simply for transmitting visible light to a remote location. Complex telephony and data communication systems may transmit multiple specific optical signals. These devices couple fibers in an end-to-end relationship, with the coupling being one source of light loss. Precision alignment of two polished ends of fibers is needed to ensure that overall optical loss in a fiber link is equal or less than the specified optical connector loss budget for a system. For single-mode telecommunication-grade fiber, this typically corresponds to connector fiber alignment tolerances that are less than 1000 nm. This means that in both parallel fiber and single fiber links, operating at multi-gigabit rates, the components applied to align the fibers must be assembled and fabricated with sub-micron precision.

In an optical fiber connection, an optical fiber connector terminates the end of a cable that contains one or multiple fibers, and enables quicker connection and disconnection than splicing. The connectors mechanically couple and align the cores of fibers so that light can pass end-to-end. Better connectors lose very little light due to reflection or misalignment of the fibers. Connectors, in both parallel/multiple fiber and single fiber links, operating at multi-gigabit rates must be assembled with subcomponents fabricated with sub micron precision. As if producing parts with such precision levels were not challenging enough, for the resulting end product to be economical it must be done in a fully automated, very high-speed process.

Current optical fiber connectors have not changed in basic design for many years. The basic connector unit is a connector assembly. FIG. **1** illustrates an example of an optical fiber connector **1400** for a cable **1410** containing optical fibers **1412**, which is commercialized by US Conec Ltd. The connector includes an assembly of components consisting of a ferrule **1402**, a ferrule housing **1404**, a cable jacket or boot **1406**, alignment guide pins **408**, and other hardware provided within or outside the housing (e.g., cable strain relief, crimp, biasing spring, spacer, etc.). The ferrule **1402** and the terminating end faces of the fibers **1412** are polished. The ferrule **1402** in the optical fiber connector **1400** is spring-loaded to provide an axial bias to press together the polished end faces of the fibers in two connectors in an end-to-end configuration. In most cases, the intent is to establish physical contact between coupled fibers to prevent loss of light. Physical contact avoids a trapped layer of air between two fibers, which increases connector insertion loss and reflection loss. An adaptor, not shown, is required to securely couple the ferrules of two connectors (the ferrule housing **1404** of each connector is plugged into the adaptor).

The optical fiber connector illustrated in FIG. **1** manufactured by US Conec Ltd. is purportedly in accordance with the structure disclosed in U.S. Pat. No. 5,214,730, which is assigned to Nippon Telegraph and Telephone Corporation. As illustrated in the '730 patent, the optical fiber connector receives a optical fiber ribbon cable having a plurality of individual optical fibers and maintains the individual optical fibers in a predetermined relationship. The optical fiber connector can be mated with another optical fiber connector (e.g., using an adaptor) so as to align the plurality of individual optical fibers of one optical fiber connector with the plurality of optical fibers of the other optical fiber connector.

The ferrule **1402** from US Conec Ltd. is generally in the form of a plastic block having a series of over-sized through-holes that provide sufficient clearance for inserting the terminating ends of optical fibers **1412** and alignment pins **1408** into the block. The ferrule **1402** is formed by molding of a plastic polymer that is often reinforced by glass particles. To insert the terminating ends of the multiple optical fibers **1412** through the holes in the ferrule block **1402**, the protective jacket and buffer (resin) layers of the optic fiber are stripped off to expose the cladding layer near the terminating ends, and the cladding layer is coated with a layer of epoxy. The terminating ends of the optical fibers are then threaded into the over-sized holes in the ferrule. The ends of the optical fibers **1412** are securely held in the ferrule **1402** upon curing of the epoxy. Similarly, the alignment pins **1408** are retained with epoxy after inserting into the oversized holes in the ferrule **1402** provided for the pins.

The above described ferrule has several significant drawbacks. The injection molded structure inherently does not hold tolerance well. The polymer is not rigid and deforms when loads (forces or moments) are applied to the fiber cable or connector housing. Polymers are also susceptible to creep and thermal expansion/contraction over longer periods of time. The clearance in the over-sized holes in the ferrule further affects tolerance of end-to-end alignment of fibers. The epoxy shrinks upon curing, which leads to bending of the plastic ferrule. Further, epoxy creeps over time, leading to pistoning or retracting of the optical fiber ends (which are pushed against the ends of adjoining fibers) within the holes in the ferrule under the applied axial bias of the spring-load in the connector. This compromises the integrity of the surface contact interface of opposing fiber end faces. These and other deficiencies result in poor resultant tolerance that is more to be desired for modern day optical fiber applications. The above noted deficiencies are further exacerbated for high density optical fiber connectors supporting a two-dimensional array of optical fibers. Fiber alignment becomes even more critical for the two-dimensional array of fibers.

Currently, it is generally accepted that fiber connectors cost too much to manufacture and the reliability and loss characteristics are more to be desired. The tolerance of the fiber connectors must improve, and the cost of producing fiber connectors must decrease if fiber optics is to be the communication media of choice for short haul and very short reach applications. The relatively widespread and ever increasing utilization of optical fibers in communication systems, data processing and other signal transmission systems has created a demand for satisfactory and efficient means of inter-joining fiber terminals.

It is therefore desirable to develop a new optical fiber connector design, and in particular a new ferrule design, which results in low insertion loss and low return loss, which provides ease of use and high reliability with low environmental sensitivity, and which can be fabricated at low cost.

SUMMARY OF THE INVENTION

The present invention provides a ferrule for an optical fiber connector, which overcomes many of the drawbacks of the prior art ferrules and optical fiber connectors. The ferrule in accordance with the present invention provides an optical fiber connector, which results in low insertion loss and low return loss, which provides ease of use and high reliability with low environmental sensitivity, and which can be fabricated at low cost. In accordance with the present invention, a compliant structure is provided on the ferrule, which clamps the alignment pins to accurately and precisely locate the alignment pins for alignment to another complementary optical fiber connector. The compliant structure supports the alignment pins with no clearance, thus not requiring epoxy to fill any clearance between alignment pins and supporting structure. The compliant structure is defined by a structure that is capable of elastic bending (e.g., a flexure defined by a cantilevered structure), as opposed to compressive deformation (e.g., interference fit or press fit between two adjoining surfaces).

In one aspect of the present invention, the compliant structure is defined by at least a flexure in the form of a cantilevered structure extending at a side of the ferrule. The cantilevered structure, with or without a complementary support structure, defines a space in which an alignment pin can be supported. In one embodiment, the flexure is defined by one or more slots provided on the body of the ferrule to facilitate bending of the extended cantilevered structure. The slots may be provided on the interior or exterior of the ferrule body. Two or more cantilevered structures may be provided to define the compliant clamping structure. In one embodiment, the alignment pin is clamped in the space defined by the compliant structure in a 3-point contact or a 4-point contact.

In one embodiment, the ferrule comprises two ferrule halves. At least one of the ferrule halves comprises grooves defined thereon for supporting optical fibers. A compliant structure is provided on the ferrule, which comprises a flexure provided on at least one of the ferrule halves.

In another embodiment, the ferrule comprises a ferrule insert having grooves for supporting optical fibers, and a ferrule frame that supports the ferrule insert and alignment pins. The compliant structure is provided on the frame, which supports alignment pins. In one embodiment, the ferrule insert comprises one or more ferrule plates having optical fiber grooves defined thereon. In one embodiment, the ferrule frame comprises a front frame section and a rear frame section. The front frame section is attached to the front end of the ferrule insert and the rear frame section is attached to the rear end of the ferrule insert to complete the ferrule structure. The alignment pins are inserted into compliant structures provided on the front and rear frame sections. In another embodiment, the ferrule frame may be a single, unitary structure, on which the ferrule insert is supported.

In a further embodiment, the ferrule insert comprises an offset structure provided with optical fiber grooves at its perimeter. In one embodiment, fiber grooves are provided at more than one surface at the perimeter of the offset structure, which can accommodate optical fibers from more than one fiber cable. A compliant structure is provided on the ferrule insert, which supports the alignment pins. The ferrule frame has a section that covers at least the fiber grooves on the ferrule insert. In one embodiment, the ferrule frame comprises extending flat covers covering the grooves provided on the offset structure. In another embodiment, the ferrule frame surrounds the perimeter of the ferrule insert.

In another aspect of the present invention, the inventive ferrules are precision formed by high throughput processes, such as stamping and extrusion.

In one embodiment, the ferrule body is made of a metal material, which may be chosen to have high stiffness (e.g., stainless steel), chemical inertness (e.g., titanium), high temperature stability (nickel alloy), low thermal expansion (e.g., Invar), or to match thermal expansion to other materials (e.g., Kovar for matching glass).

The ferrule in accordance with the present invention overcomes many of the deficiencies of the prior art, resulting in an optical fiber connector that results in low insertion loss and low return loss, which provides ease of use and high reliability with low environmental sensitivity, and which can be fabricated at low cost.

BRIEF DESCRIPTION OF THE DRAWINGS

For a fuller understanding of the nature and advantages of the invention, as well as the preferred mode of use, reference should be made to the following detailed description read in conjunction with the accompanying drawings. In the following drawings, like reference numerals designate like or similar parts throughout the drawings.

FIG. **1** illustrates a prior art optical fiber connector.

FIG. **2** illustrates a perspective view of an optical fiber connector in accordance with one embodiment of the present invention.

FIG. **3** is an end view of the optical fiber connector in FIG. **2**.

FIG. **4** is a side view of the optical fiber connector in FIG. **2**.

FIG. **5** is a sectional view of a portion of the lower ferrule halve, in accordance with another embodiment of the present invention.

FIG. **6** illustrates a perspective view of an optical fiber connector in accordance with a further embodiment of the present invention.

FIG. **7** is an end view of the optical fiber connector in FIG. **6**.

FIG. **8** illustrates a perspective view of an optical fiber connector in accordance with a yet another embodiment of the present invention.

FIG. **9** is an end view of the optical fiber connector in FIG. **8**.

FIG. **10** illustrates a perspective view of an optical fiber connector in accordance with a further embodiment of the present invention.

FIG. **11** is an end view of the optical fiber connector in FIG. **10**.

FIG. **12** illustrates a perspective view of an optical fiber connector in accordance with a further embodiment of the present invention.

FIG. **13** is an end view of the optical fiber connector in FIG. **12**.

FIG. **14** illustrates a perspective view of an optical fiber connector in accordance with a further embodiment of the present invention.

FIG. **15** is an end view of the optical fiber connector in FIG. **14**.

FIG. **16** is a side view of the optical fiber connector in FIG. **14**.

FIG. **17** is an exploded view of the optical fiber connector in FIG. **14**.

FIG. **18** is a partially assembled view of the optical fiber connector in FIG. **14**.

FIG. **19** is a partially assembled view of a variation of optical fiber connector of the embodiment of FIG. **14**.

FIG. **20** is a partially assembled view of another variation of optical fiber connector of the embodiment of FIG. **14**.

FIG. **21** illustrates a perspective view of an optical fiber connector in accordance with a further embodiment of the present invention.

FIG. **22** is partially assembled view of the optical fiber assembly in FIG. **21**.

FIG. **23** is an end view of the optical fiber connector in FIG. **21**.

FIG. **24** is top view of the optical fiber connector in FIG. **21**.

FIG. **25** illustrates a perspective view of a ferrule insert of the optical fiber connector in FIG. **21**.

FIG. **26** illustrates a perspective view of a ferrule insert in accordance with another embodiment of the present invention.

FIG. **27** illustrates a perspective view of a ferrule insert in accordance with further embodiment of the present invention.

FIG. **28** illustrates a perspective view of an optical fiber connector in accordance with yet a further embodiment of the present invention.

FIG. **29** is an exploded view of the optical fiber connector in FIG. **28**.

FIG. **30** is an end view of the optical fiber connector in FIG. **28**.

FIG. **31** is a top view of the optical fiber connector in FIG. **28**.

FIG. **32** is a side view of the optical fiber connector in FIG. **28**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

This invention is described below in reference to various embodiments with reference to the figures. While this invention is described in terms of the best mode for achieving this invention's objectives, it will be appreciated by those skilled in the art that variations may be accomplished in view of these teachings without deviating from the spirit or scope of the invention.

The present invention provides a ferrule for an optical fiber connector, which overcomes many of the drawbacks of the prior art ferrules and optical fiber connectors. The ferrule in accordance with the present invention provides an optical fiber connector, which results in low insertion loss and low return loss, which provides ease of use and high reliability with low environmental sensitivity, and which can be fabricated at low cost. In accordance with the present invention, a compliant structure is provided on the ferrule, which clamps the alignment pins to accurately and precisely locate the alignment pins for alignment to another complementary optical fiber connector. The compliant structure supports the alignment pins with no clearance, thus not requiring epoxy to fill any clearance between alignment pins and supporting structure. The compliant structure is defined by a structure that is capable of elastic deformation, preferably bending (e.g., a flexure defined by a cantilevered structure), as opposed to compressive or tensile deformation (e.g., interference fit or press fit between two adjoining surfaces). In one aspect of the present invention, the compliant structure is defined by at least a flexure in the form of a cantilevered structure extending at a side of the ferrule. The cantilevered structure, with or without a complementary support structure, defines a space in which an alignment pin can be supported.

FIG. **2** illustrates a perspective view of an optical fiber connector **10** having an assembly of components including a ferrule **12** in accordance with one embodiment of the present invention. The connector **10** further includes a ferrule housing **14** (shown in dotted lines), a cable boot **16** (shown in dotted lines), and alignment guide pins **18**. FIG. **2** is a simplified illustration of the optical fiber connector **10**. Other than the ferrule **12** that is structured in accordance with the present invention, the other components of the optical fiber assembly **10** may further include those found in the optical fiber assembly shown in FIG. **1** (i.e., the ferrule in accordance with the present invention may be made backward compatible to be used in MTO/MPO optical fiber connectors as offered by US Conec Ltd.). FIGS. **3-4** are various views of the optical fiber connector **10**, with the ferrule housing **14** and cable boot **16** omitted from view (for simplicity, further embodiments are discussed herein below and illustrated with the ferrule housing **14** and cable boot omitted from view).

In the illustrated embodiment, the ferrule **12** comprises first and second ferrule halves **12***a* and **12***b*. Referring also to FIG. **3**, each ferrule halves (**12***a*, **12***b*) has a generally rectangular plate structure. The ferrule **12***b* has an open structure that has a row of open grooves **24** precisely formed thereon in a plane for accommodating optical fibers **20** of an optical fiber cable **22**. (While a ribbon type fiber cable is illustrated, one can appreciate instead of ribbon fiber cables, the optical fibers may be bundled in the form of rounded fiber cables, without departing from the scope and spirit of the present invention.) The two ferrule halves **12***a* and **12***b* are stacked in a mating configuration, with the ferrule halve **12***a* covering the grooves **24** in the ferrule halve **12***b*. In the illustrated embodiment, twelve optical fibers **20** are held within a jacket **27** to form an optical ribbon fiber cable **22**. The terminating optical fibers **20** of the optical fiber cable **22** are received in the row of longitudinal grooves **24** of the second ferrule halve **12***b*. The grooves **24** receive the terminating end sections of the optical fibers **20** in their bare form with cladding exposed, without protective buffer and jacket layers. (In the discussion throughout below, in connection with receiving optical fibers in ferrule grooves, it is understood that the terminating end sections of the optical fibers are in their bare form with cladding exposed, without protective buffer and jacket layer.)

Referring also to FIG. **4**, the tail sections (**26***a*, **26***b*) of the ferrule halves **12***a* and **12***b* are thinner than the head sections (**36***a*, **36***b*). The facing sides of the tail sections (**26***a*, **26***b*) together define a recess **28** there-between, which is sized to receive and clamp the jacket **27** between the ferrule halves **22***a* and **22***b* when they are mated together in the configuration illustrated in FIGS. **2** and **4**. The jacket **27** of the ribbon fiber cable **22** is fitted within the recess **28**, which provides additional room to accommodate the thickness of the jackets (**27***a* and **27***b*) and the protective buffer and jacket layers on the fibers **20** within the jacket **27**. The rear sections (**26***a*, **26***b*) together provide strain relief on the fiber cable **22**. At least the head sections (**36***a*, **36***b*) of the ferrule halves are maintained in a mating configuration by laser welding, for example. Alternatively, the ferrule may further comprise a collar or sleeve (not shown) to maintain the head sections (**36***a*, **36***b*) of the ferrule halves (**12***a*, **12***b*) in a mating configuration.

The configuration of the rows of grooves is more clearly seen from the end view of the ferrule **12** in FIG. **3**. In the illustrated embodiment, each groove has a substantially U-shaped cross-section with substantially parallel sides. The head sections **36***a* and **36***b* of the ferrule halves **12***a* and **12***b* are mated with the head section **36***a* of the first ferrule halve **12***a* completely covering the opposing groove openings in the head section **36***b* of the second ferrule halve **12***b*.

The depth of the grooves **24** is sized to completely receive the optical fibers **20**. In the illustrated embodiment, the depth of the grooves is at least D (e.g., 125 μm), the diameter of the bare section of the optical fibers, with cladding exposed, without protective buffer and jacket layers, as referenced throughout herein. With the depth of the grooves being substantially D, the flat underside of the head section **36***a* of the first ferrule halve **20***a* and the opposing grooves **24** together define a space that precisely positions the optical fibers **20**.

The width of the longitudinal opening defined between the walls along at least a section of the grooves is slightly narrower than the diameter of the bare optical fibers to create a tight fit (e.g., an interference fit of 1 μm) with respect to the bare fibers (bare sections with cladding exposed, without protective buffer and jacket layers), which allows the end section of an optical fiber **20** to be inserted laterally into the longitudinal opening of groove, but which snuggly retains the optical fiber in the groove **24**. The grooves **24** and the width of the longitudinal groove openings are shaped and sized to retain the fibers without any clearance to allow for movement of the fibers **24** relative to the grooves. The grooves **24** may have a rounded bottom to conform to the external shape of the optical fiber (as illustrated), or a flat bottom or a v-groove (thus resulting in spaces between the fiber and the wall of the groove, which may be filled with an additional material such as epoxy for encapsulation purpose, to prevent the entrapment of particles, especially during mechanical polishing of the ferrule end face). The rounded bottom is preferable since it increases the contact area with the fiber and provides more uniform elastic stress within the fiber. The use of a groove with an interference fit contrasts with that of the molded ferrule as shown in FIG. **1**, which has a hole that is toleranced to be larger than the diameter of the optical fiber. Consequently, the oversized hole does not govern the position of the optical fiber in the prior art.

Given that the optical fibers **20** are completely retained in the grooves **24**, the optical fibers **20** are positioned with precision between the ferrule halves (**12***a*, **12***b*) by the grooves **24***a*. The position and orientation of the optical fibers **20** is set by the location and parallelism of the grooves **24**. Accordingly, the relative locations (e.g., spacing) of the optical fibers **20** in the ferrule halves (**12***a*, **12***b*) are precisely maintained within the ferrule, e.g., for alignment to fibers in an opposing optical fiber connector (which has a female structure to receive the alignment pins **18**). No complementary ferrule would be required to securely and precisely position the fibers within the optical fiber connector, as such a complementary ferrule halve do not serve any alignment function or effective support to position the fibers **20** in the ferrule halve **12***b*. However, by providing the top ferrule halve **12***a*, it serves as a cover for the grooves **24** to prevent accidental dislodgment of the optical fibers **20**.

In accordance with the present invention, a compliant structure is provided on the ferrule **12** for precisely locating the alignment pins **18** with respect to the fiber grooves **24**. The compliant structure comprises a flexure provided on at least one of the ferrule halves (**12***a*, **12***b*). In one embodiment, the flexure is defined by one or more slots provided on the body of the ferrule to facilitate bending of the extended cantilevered structure. The slots may be provided on the interior or exterior of the ferrule body.

FIGS. **2**-**3** illustrate slots provided on the exterior of the ferrule **12**. In particular, near each lateral side **44** of the top ferrule halve **12***a*, a longitudinal narrow slot **40** is provided at the top side of the ferrule halve **12***a*, which extends from the head section **36***a* to the tail section **26***a*. In the end view of FIG. **3**, the slots **40** are vertical to the top exterior surface of the ferrule halve **12***a*. The slot **40** reduces the thickness of the top ferrule halve **12***a*, such that the side portion **44** extends from the base portion **45** of the first ferrule halve **12***a* via a cantilever link **42** (i.e., the side portions **44** are cantilevered structures with respect to the base portion **45**). A beveled surface **49***a* is provided in the first ferrule halve **12***a* facing towards the side portion **44**, and a beveled surface **49***b* is provided in the second ferrule halve **12***b* facing towards the side portion **44**. The side portion **44**, the beveled surface **49***a* and the beveled surface **49***b* together define a space **48** for precisely locating an alignment pin **18** with respect to the optical fibers **20** (i.e., resulting in a 3-point contact). Upon insertion of an alignment pin **18** in the space **48**, the cantilever link **42** elastically deforms (flexes) to allow the side portion **44** to displace slightly outwards away from the base portion **45**, thereby providing an inward bias to clamp the alignment pins **18** against the beveled surfaces of the ferrule halves.

Given that the beveled surfaces **49***a* and **49***b* are closest to the fiber grooves **24**, these beveled surfaces are essentially reference planes that can be precisely formed, while the cantilevered side portions **44** are allowed certain flexibility in movement without affecting the precise reference planes. In another aspect of the present invention, the fiber grooves of the above-disclosed embodiment are precision formed by high throughput processes, such as stamping and extrusion. The surface structures of the ferrule components (i.e., the ferrules halves **12***a* and **12***b*) lend themselves to forming using such high throughput processes. A precision stamping process and apparatus has been disclosed in U.S. Pat. No. 7,343,770, which was commonly assigned to the assignee of the present invention. This patent is fully incorporated by reference as if fully set forth herein. The process and stamping apparatus disclosed therein may be adapted to precision stamping the ferrules of the present invention.

In one embodiment, the ferrule body is made of a metal material, which may be chosen to have good thermal dimensional stability (e.g., Invar).

In another embodiment of the present invention, the second ferrule halve **12***b* has an open structure with precision groove clamping features formed thereon, which can securely hold optical fibers without the need for epoxy or a complementary precision part. FIG. **5** illustrates a section of the grooves **24** in the head section **36***b* of the second ferrule halve **12***b*.

The grooves **24***b* are structured to securely retain the fibers **20** (bare sections with cladding exposed, without protective buffer and jacket layers) by an opening that clamps the fibers **20**, e.g., by interference fit (or press fit). The interference fit assures that the fibers **20** are clamped in place and consequently the position and orientation of the fibers is set by the location and parallelism of the grooves **24**. The use of an interference fit contrasts with that of the molded ferrule as shown in FIG. **1**, which has a hole that is toleranced to be larger than the diameter of the optical fiber. Consequently, the oversized hole does not govern the position of the optical fiber.

In the embodiment illustrated in FIG. **5**, the width W of the longitudinal opening **23** of the grooves **24** is made slightly narrower than the diameter of the optical fibers **20**. In particular, the opening **23** is defined by lips **25** formed at the opposing longitudinal edges of the longitudinal opening **23**. The width W of the longitudinal openings **23** is slightly undersized to allow the terminating end section of the optical fibers to be inserted laterally into the longitudinal openings **23** of the grooves with an interference fit. The magnitude of interference can be set by the manufacturing process so that loading the fiber into the groove causes only elastic deformation or minor plastic deformation in the lip. The grooves should not be plastically deformed; otherwise it will affect the accuracy of the fiber locations.

Specifically, to attach the fibers **20** to the head section **36***b* of the ferrule **12***b*, the terminating end section of the fibers **20** are pressed lengthwise into the grooves **24** through the longitudinal openings **23** with a snap action (i.e., not in the axial direction of the grooves), with the tip of the fibers **20** slightly protruding beyond the end face of the head section **36***b*. Further, the width W of the longitudinal openings **23** and the grooves **24** are sized and shaped to snuggly retain the section of optical fibers **20** in the grooves **24** without providing any clearance for axial and lateral movements of the end face of the fibers relative to the grooves to ensure tight tolerance for optical coupling between end faces of two adjoining fibers. No epoxy would be required for retaining the bare fiber sections in the grooves given the interference along the mating surfaces between the fibers **20** and the grooves **24**.

The embodiment shown in FIG. **5** illustrates the cross-sectional shape of the grooves **24** generally conforming to the body of the fibers **20**. The fiber **20** is securely "clamped" within the groove **24**, with the lips **25** pressing on the top of the fiber **20** against the bottom and other parts of the groove **24**. In the illustrated embodiment, the wall of the fiber **20** is shown to press against the entire wall of the groove **24**, except near the opening **23**. This provides a substantially uniform pressure on substantially the entire circumference of the fiber, which has less effect on the optical signals transmitted through the fiber **20** due to stress-induced changes in fiber or core indices of refraction. However, it is well within the scope and spirit of the present invention to structure the grooves in the ferrule with different cross-sections that would still provide adequate interference fit to securely retain the fibers **20** in the grooves **24**. For example, the grooves may have a flat or curved bottom, curved sidewalls, or flat sidewalls perpendicular or at a slight divergent angle to the flat bottom (e.g., a v-bottom), and inwardly directing lips to define the longitudinal opening of the groove. These groove configurations would result in certain spaces between the curved fiber walls and the flat or curved sidewalls of the groove, but the clamping action by the lips **25** and/or vertical walls of the grooves against the fiber nonetheless would not provide any clearance to allow for movement of the fibers within the groove. The empty spaces may be filled with an additional material such as epoxy for encapsulation purpose, to prevent the entrapment of particles, especially during mechanical polishing of the ferrule end face.

Given that the fiber **20** is completely retained in the groove **24**, and the profile of the groove such as lips **25** and the bottom of the groove dictate the location of the fiber **20** within the groove, the fiber **20** is positioned with precision in the ferrule by the groove. Accordingly, the relative locations (e.g., spacing) of the fibers **20** in the ferrule halve **12***b* are precisely maintained within the ferrule, e.g., for alignment to fibers in an opposing optical fiber connector (which has a female structure to receive the alignment pins **18**).

As an example and not limitation, in one embodiment, for optical fibers **20***b* made of silica and having a diameter of 125 μm, in a ferrule made of kovar (54% Fe, 29% Ni, 17% Co) material, the length of the grooves **24***b* may be 1 to 3 mm, the diameter or width (i.e., the maximum lateral dimension D) of the grooves **24***b* is 0.124 mm, and the width W of the longitudinal openings **23** is 105 μm. The sidewalls of the groove **23** tilt inward towards the opening **23** at an angle θ of about 5 to 20 degrees with respect to the vertical tangent to the fiber **20***b*. The interference provided is about 1 μm, appropriate for the silica and kovar material. The silica glass is very high strength in compression, so it will withstand high contact pressures from the interference fit.

For a ferrule having the groove clamping structure in accordance with FIG. **5**, no complementary ferrule would be required to securely and precisely position the fibers within the optical fiber connector. Even though complementary ferrule halves do not serve any alignment function or effective support to position the fibers **20***b* in the ferrule halve **12***b*, and vice versa, however, by providing two ferrule halves **12***a* and **12***b* each having the above groove clamping structure, the ferrule halves **12***a* and **12***b* together form a ferrule **12** that accommodates a high fiber density.

It can be appreciated from the foregoing that open channels or grooves can be more easily and precisely formed, compared to forming through-holes in a plastic ferrule block practiced in the prior art, such as the connector shown in FIG. **1**. In one embodiment, the grooves are initially formed (e.g., by precision stamping), followed by narrowing of the openings of the grooves, for example, by stamping or punching the top surface of the ferrule body to push the material at the two opposing edges of the opening into the opening in the groove to form a lip, or laser machining to melt the material at the corners of the opening to flow into the opening of the groove to form a lip. In another embodiment, the clamping grooves may be precision formed by extrusion. Further information on the high throughput forming of the clamping grooves shown in FIG. **5** has been disclosed in U.S. patent application Ser. No. 13/440,970, filed Apr. 5, 2012, which was commonly assigned to the assignee of the present invention. This application is fully incorporated by reference as if fully set forth herein.

In the embodiment of FIGS. **2**-**4**, for each alignment pin **18**, the compliant structure includes one flexure, providing a 3-point contact (sectional view) between the alignment pins and the ferrule halves. FIGS. **6** and **7** illustrate an alternate embodiment in which a compliant structure includes two flexures, providing a 4-point contact between the alignment pins and the ferrule halves. With the exception of the ferrule, the general structure of the optical fiber connector **110** in this embodiment is similar to the structure of the optical fiber connector **10** in the embodiment of FIGS. **2**-**4**. The optical fiber connector **110** includes a ferrule **112** comprising two ferrule halves **112***a* and **112***b*, a ferrule housing and a cable boot (similar to those shown in FIG. **2** but are omitted from view for simplicity). The ferrule halves (**112***a*, **112***b*) are provided with grooves **24** for supporting optical fibers **20**. The general structure of the fiber grooves **24** is similar to the structure of the grooves in FIG. **2** (or the alternate embodiment of FIG. **5**).

Comparing to the previous embodiment, additional slots are provided on the exterior of the second (lower) ferrule **112***b*. Specifically, near each lateral side **144***a* of the first ferrule halve **112***a*, a longitudinal narrow slot **140***a* is provided at the outside top side of the ferrule halve **112***a*, which extends from the head section **136***a* to the tail section **126***a* of the ferrule halve **112***a*. In addition, near each lateral side **144***b* of the second ferrule halve **112***b*, a longitudinal narrow slot **140***b* is provided at the outside underside side of the ferrule halve **112***b*, which extends from the head section **136***b* to the tail section **126***b* of the ferrule halve **112***b*. In the end view of FIG. **7**, the slots **140***a* and **140***b* are vertical to the exterior surfaces of the ferrule halves **112***a* and **112***b*. The design considerations and purposes for the slots (**140***a*, **140***b*) are similar to the slots **40** in the previous embodiment. In particular, the slots (**140***a*, **140***b*) reduce the thickness of the top and second ferrule halves (**112***a*, **112***b*) such that the side portions

(**144**a, **144**b) extend from the base portions (**145**a, **145**b) of the first and second ferrule halves (**112**a, **112**b) via cantilever links (**142**a, **142**b) (i.e., the side portions (**144**a, **144**b) are cantilevered structures with respect to the base portions (**145**a, **145**b). In this embodiment, beveled surfaces **149**a and **150**a are defined by a V-groove **160** provided between the slot **140**a and the side portion **144**a in the first ferrule halve **112**a, and beveled surfaces **149**b and **150**b are defined by a V-groove **162** provided between the slot **140**b and the side portion **144**b in the second ferrule halve **112**b. The V-grooves (**160**, **162**) extend through the ferrule halves (**412**a, **412**b) from the head sections (**436**a, **436**b) to the tail sections (**426**a, **426**b). At each alignment pin region, the beveled surfaces **149**a, **149**b, **150**a and **150**b together define a space **148** for precisely locating an alignment pin **18** with respect to the optical fibers **20** (i.e., resulting in a 4-point contact). Upon insertion of an alignment pin **18** in the space **148**, the cantilever links (**142**a, **142**b) elastically deform to allow the side portions (**144**a, **144**b) to displace slightly outwards away from the base portions (**145**a, **145**b), thereby providing an inward bias to clamp the alignment pins **18** between the beveled surfaces of the ferrule halves (**112**a, **112**b).

Given that the beveled surfaces **149**a and **149**b are closest to the fiber grooves **24**, these beveled surfaces are essentially reference planes that can be precisely formed, while the cantilevered side portions (**144**a, **144**b) are allowed certain flexibility in movement without affecting the precise reference planes.

In the previous two embodiments of FIGS. **2**-**7**, the slots are provided on the exterior surfaces of the ferrule halves. Referring to FIGS. **8** and **9**, alternatively, the slots may be provided on the interior surfaces of the ferrule halves. FIGS. **8** and **9** illustrate an embodiment of an optical fiber connector **210**, in which a compliant structure includes two flexures defined by slots (**240**a, **240**b) provided on the interior surfaces of the ferrules halve (**212**a, **212**b), providing a 4-point contact between the alignment pins and the ferrule halves. With the exception of the ferrule, the general structure of the optical fiber connector **210** in this embodiment is similar to the structure of the optical fiber connector **110** in the embodiment of FIGS. **6**-**7**. The optical fiber connector **210** includes a ferrule **212** comprising two ferrule halves **212**a and **212**b, a ferrule housing and a cable boot (similar to those shown in FIG. **2** but are omitted from view for simplicity). The ferrule halves (**212**a, **212**b) are provided with grooves **24** for supporting optical fibers **20**. The general structure of the fiber grooves **24** is similar to the structure of the grooves in FIG. **2** (or the alternate embodiment of FIG. **5**).

Comparing to the previous embodiment of FIGS. **6**-**7**, slots are provided on the interior or facing surfaces of the first and second ferrules (**212**a, **212**b). Specifically, near each lateral side **244**a of the first ferrule halve **212**a, a longitudinal narrow slot **240**a is provided at the inside underside of the ferrule halve **212**a, which extends from the head section **236**a to the tail section **226**a of the top ferrule halve **212**a. In addition, near each lateral side **244**b of the second ferrule halve **212**b, a longitudinal narrow slot **240**b is provided at the inside topside of the lower ferrule halve **212**b, which extends from the head section **236**a to the tail section **226**b of the ferrule halve **212**b. In the end view of FIG. **9**, the slots **240**a and **240**b are vertical to the interior surfaces of the ferrule halves **212**a and **212**b. Pin clamping beveled surfaces **249**a, **249**b, **250**a, **250**b are defined by V-grooves (**260**a, **260**b) provided on the ferrule halves (**212**a, **212**b), similar to the beveled surfaces **149**a, **149**b, **150**a and **150**b in the previous embodiment. The internal slots (**240**a, **240**b) extend from the bottom of the V-grooves (**260**a, **260**b) into the ferrules halves (**212**a, **212**b).

The design considerations and purposes for the slots (**240**a, **240**b) are similar to the slots **40** and **140** in the previous embodiments. In particular, the slots (**240**a, **240**b) reduce the thickness of the top and second ferrule halves (**212**a, **212**b) such that the side portions (**244**a, **244**b) extend from the base portions (**245**a, **245**b) of the first and second ferrule halves (**212**a, **212**b) via cantilever links (**242**a, **242**b) (i.e., the side portions (**244**a, **244**b) are cantilevered structures with respect to the base portions (**245**a, **245**b). At each alignment pin region, the beveled surfaces **249**a, **249**b, **250**a and **250**b together define a space **248** for precisely locating an alignment pin **18** with respect to the optical fibers **20** (i.e., resulting in a 4-point contact). Upon insertion of an alignment pin **18** in the space **248**, the cantilever links (**242**a, **242**b) elastically deform to allow the side portions (**244**a, **244**b) to displace slightly outwards away from the base portions (**245**a, **245**b), thereby providing an inward bias to clamp the alignment pins **18** between the beveled surfaces of the ferrule halves (**212**a, **212**b).

FIGS. **10** and **11** illustrate an alternate embodiment of an optical fiber connector in which the compliant structure is a variation of the embodiment of FIGS. **8** and **9**. With the exception of the ferrule, the general structure of the optical fiber connector **310** in this embodiment is similar to the structure of the optical fiber connector **210** in the embodiment of FIGS. **8**-**9**. The optical fiber connector **310** includes a ferrule **312** comprising two ferrule halves **312**a and **312**b, a ferrule housing and a cable boot (similar to those shown in FIG. **2** but are omitted from view for simplicity). The ferrule halves (**312**a, **312**b) are provided with grooves **24** for supporting optical fibers **20**. The general structure of the fiber grooves **24** is similar to the structure of the grooves in FIG. **9**. Comparing to FIG. **9**, the difference in the embodiment of FIG. **11** is that the internal slots **340**a and **340**b are provided at an angle to the interior surfaces of the ferrule halves **312**a and **312**b, as shown in the end view of FIG. **11**, instead of being vertical to the interior surfaces of the ferrule halves as in the case of FIG. **9**.

FIGS. **12** and **13** illustrate an alternate embodiment of an optical fiber connector **410**. In this embodiment, instead of slots defining flexure in the ferrule halves, a flexure is defined by a beam cantilevered above a space in a ferrule halve. With the exception of the ferrule, the general structure of the optical fiber connector **410** in this embodiment is similar to the structure of the optical fiber connector **10** in the embodiment of FIGS. **2**-**4**. The optical fiber connector **410** includes a ferrule **412** comprising two ferrule halves **412**a and **412**b, a ferrule housing and a cable boot (similar to those shown in FIG. **2** but are omitted from view for simplicity). The ferrule halve **412** is provided with grooves **24** for supporting optical fibers **20**. The general structure of the fiber grooves **24** is similar to the structure of the grooves in FIG. **3**.

In this embodiment, the compliant structure is defined by a flexure that comprises a cantilevered beam **442** suspended above a space **440** provided in the lower (second) ferrule **412**b. Pin clamping beveled surfaces **249** defined by a V-groove **460** are provided on the first ferrule halve **412**a. A square bottom groove or square channel **462** is provided in the second ferrule plate **412**b, defining a flexure surface **450**. The V-grooves **460** and the square bottom grooves **462** extend through the ferrule halves (**412**a, **412**b) from the head sections (**436**a, **436**b) to the tail sections (**426**a, **426**b). At each alignment pin region, the beveled surfaces **449** and the flexure surface **450** together define a space **448** for precisely locating an alignment pin **18** with respect to the optical fibers **20**. The flexure surface **450** of the beam **442** and the beveled surfaces **449** defined a 3-point contact for the alignment pin **18**. The

V-groove **460** provides a precise reference location for the alignment pin. The beam **442** is allowed to elastically deform (flex slightly) and towards the space **440** below. Upon insertion of an alignment pin **18** in the space **448**, the suspended beam **442** elastically deforms (flexes) slightly downwards and onto the space **440**, thereby providing an upward bias to clamp the alignment pins **18** against the beveled surfaces of the V-groove **460** in the first ferrule halve **412***a*.

In the embodiment shown in FIG. **13**, the compliant structures for the alignment pins **18** are defined by a combination of a V-groove provided on one ferrule halve and a square bottom groove provided on the other ferrule halve. The V-groove **460** can be precisely formed (e.g., by precision stamping), and the depth of the square bottom groove **462** can be precisely formed without requiring precision forming the walls of the square bottom groove **462**. Variations in lateral dimension of the square groove **462** do not affect pin alignment. When the head sections (**436***a*, **436***b*) are mated together, the combination of the precisely defined beveled surfaces **459** of the V-groove **460** and the precise depth of the flexure surface **450** square bottom groove **462** accurately and precisely position the alignment pins **18**.

While the first ferrule **412***a* is provided with V-grooves **460** and the second ferrule **412***b* is provided with the cantilever beam (square channel **462** and space **440**), it is well within the scope and spirit of the present invention to provide a V-groove and a cantilever beam in each ferrule halve (not shown). In an alternate embodiment (not shown), the ferrule halves may be made more symmetrical. Instead of only one ferrule halve providing grooves for optical fibers, each ferrule halve may be structured with a head section having semicircular cylindrical grooves for supporting optical fibers. The compliant structure for clamping the alignment pins may also be made symmetrical. Symmetrical ferrule halves would facilitate inventory management of identical components. However, the ferrule halves need not be identical, as long as they are capable of being mated together to support the optical fibers **20**.

FIGS. **14-18** illustrate another embodiment of an optical fiber connector **510**. In this embodiment, the ferrule **590** comprises a ferrule insert **512** having grooves **24** for supporting optical fibers **20**, and a ferrule frame **552** that supports the ferrule insert **512** and alignment pins **18**. In the illustrated embodiment, the ferrule insert **512** comprises a lower ferrule plate **512***a* without fiber grooves, and an upper ferrule plate **512***b* having grooves for optical fibers defined thereon (much like the ferrules **12***a* and **12***b*, or **412***a* and **412***b*, etc.). The ferrule insert **512** in this embodiment resembles the ferrules in the earlier embodiments, in that the ferrule inserts **512** are structured to clamp optical fibers **20** and the fiber cable **20** in a similar manner as the earlier described embodiments. The ferrule frame **552** comprises a front frame section **555***a* and a rear frame section **555***b*. In the illustrated embodiment, the frame sections **555***a* and **555***b* share similar structures. The head section (**536***a*, **536***b*) of the ferrule plates (**512***a*, **512***b*) are mated and inserted into an opening **565***a* in the front frame section **555***a* and the tail section (**526***a*, **526***b*) of the ferrule plates (**512***a*, **512***b*) are inserted into an opening **565***b* in the rear frame section **555***b* to complete the ferrule structure.

The compliant pin clamping structure is provided on the ferrule frame **552**, which supports the alignment pins **18**. Specifically, flexures are provided at the front frame section **555***a* and the rear frame section **555***b*. Referring to FIG. **15**, the compliant structure is similar to the internally slotted compliant structure on the ferrule **212** shown in FIG. **9**, with the exceptions that the frame sections (**555***a*, **555***b*) are each unitary or one-piece and are not provided with fiber grooves in this embodiment. The resultant compliant structure resembles a C-shaped structure, having a slit opening **570**. Pin clamping beveled surfaces **549***a*, **549***b*, **550***a*, **550***b* are defined by V-grooves (**560***a*, **560***b*) provided on the frame section (**555***a*, **555***b*), similar to the beveled surfaces **249***a*, **249***b*, **250***a* and **250***b* in the earlier described embodiment. The internal slots (**540***a*, **540***b*) extend from the bottom of the V-grooves (**560***a*, **560***b*) into the frame sections (**555**, **556**). The design considerations and purposes for the slots (**540***a*, **540***b*) are similar to the slots **40**, **140** and **240** for the ferrules described in the earlier embodiments. In particular, the slots (**540***a*, **540***b*) reduce the thickness of the frame sections (**555***a*, **555***b*) such that the side portions (**544***a*, **544***b*) extend from the base portions (**545***a*, **545***b*) of the frame sections (**555***a*, **555***b*) via cantilever links (**542***a*, **542***b*) (i.e., the side portions (**544***a*, **544***b*) are cantilevered structures with respect to the base portions (**545***a*, **545***b*). At each alignment pin region, the beveled surfaces (**549***a* and **550***a*, and **549***b* and **550***b*) together define a space (**548***a*, **548***b*) for precisely locating an alignment pin **18** with respect to the optical fibers **20** (i.e., resulting in a 4-point contact). The alignment pins are inserted into compliant structures provided on the front and rear frame sections (**55***a*, **555***b*). Upon insertion of an alignment pin **18** in the space (**548***a*, **548***b*), the cantilever links (**542***a*, **542***b*) elastically deform to allow the side portions (**544***a*, **544***b*) to displace slightly outwards away from the base portions (**545***a*, **545***b*), thereby providing an inward bias to clamp the alignment pins **18** between the beveled surfaces of the frame sections (**555***a*, **555***b*). In the illustrated embodiment, the ferrule plates (**512***a*, **512***b*) each includes a flange (**575***a*, **575***b*) extending from each side, on which a groove (**576***a*, **576***b*) is provided. When the ferrule plates (**512***a*, **512***b*) are mated together, the grooves (**576***a*, **576***b*) form guide holes for guiding the alignment pins from the front frame section **555***a* to the rear frame section **555***b*.

FIGS. **19** and **20** illustrate alternate embodiments in which the ferrule frame may be a single, unitary structure, on which the ferrule insert is supported. In the embodiment of FIG. **19**, the optical fiber connector **610** includes a ferrule **690**, which comprises a frame **652** and a ferrule insert **612** that comprises ferrule plates (**612***a*, **612***b*). The ferrule plates together form a generally flat cylindrical profile, which can be inserted through the openings **665***a* and **665***b* in the front and rear frame sections **655***a* and **655***b*. In this embodiment, the frame **652** is a unitary piece, including front and rear frame sections (**655***a*, **655***b*) connected by a bridge **680**. The bridge **680** may extend between the front and rear frame sections across the entire width of the frame **652**.

In the embodiment of FIG. **20**, the optical fiber connector **610'** comprises a ferrule **690'**, which comprises a ferrule frame **652'** and a similar ferrule insert **612** that comprises ferrule plates (**612***a*, **612***b*). The ferrule plates together form a generally flat cylindrical profile, which can be inserted through the opening **665** in the frame **652'**. Unlike the previous embodiment, the entire ferrule frame **662'** is one section. A similar compliant structure is provided, which extends from the front to the rear of the frame **652'**. The ferrule frame **652'** is provided with compliant structures, similar to that disclosed in connection with the previous embodiment.

FIGS. **21** to **25** illustrate another embodiment of an optical fiber connector **710**. It comprises a ferrule **790**, which comprises a ferrule frame **552** and a ferrule insert **512** that comprises an offset structure (resembling the shape of a "dog-bone") provided with optical fiber grooves **24** at its perimeter. Referring to FIG. **25**, a stub **777** extends from the center of ferrule insert **512** towards the frame base **755**. In the illustrated embodiment, fiber grooves (**24***a*, **24***b*) are provided at opposite surfaces at the perimeter of the offset structure, which can accommodate optical fibers (**20***a*, **20***b*) from two fiber cables (**22***a*, **22***b*).

Referring to FIG. **23**, a compliant structure is provided at two ends of the ferrule insert **512**, which supports the alignment pins **18**. In particular, the compliant structure comprises a C-shaped flexure, having fingers **744** extending around the alignment pins **18** from the base portion **745**. The fingers **744** are able to flex at the flexure links **742**, upon insertion of alignment pins. In this embodiment, the compliant structure provides essentially multiple points of contact on the alignment pin, given its partial circular opening **798** defined in the compliant structure.

The ferrule frame **752** has flat cover portions **780** that extend from the base **755** of the ferrule frame **752**. The cover portions **780** covers at least the fiber grooves (**724***a*, **724***b*) on the ferrule insert **712**. The cover portions **780** and the grooves (**724***a*, **724***b*) resemble the ferrule base portion **45** and grooves **24** for the ferrule **12** discussed in connections with FIG. **3**. Similar considerations apply here for the present embodiment, with respect to providing precise support to the optical fibers (**22***a*, **22***b*) using grooves (**24***a*, **24***b*). In particular, the grooves (**724***a*, **724***b*) can take the same structure as grooves **24** on the surface of ferrule halve **12***b* in the embodiment of FIG. **3**, or the grooves in the embodiments of FIG. **5**.

Referring to FIG. **22**, to assemble the ferrule insert **512** to the ferrule frame **752**, the jackets (**27***a*, **27***b*) of the optical fibers (**22***a*, **22***b*) are inserted through the space **728** defined between the cover portions **780** in the frame base **755**. The bare optical fibers (**20***a*, **20***b*) are inserted into the grooves (**24***a*, **24***b*) on the ferrule insert **712**. The fiber jackets (**27***a*, **27***b*) are rested against the stub **777** behind the ferrule insert **512**, and the ferrule insert **512** is inserted into the space **728** defined between the two cover portions **780**, to complete the ferrule structure illustrated in FIG. **21**.

FIGS. **26** and **27** illustrate variations of the compliant structures for ferrule inserts as compared to the ferrule insert shown in FIG. **25**. In FIG. **26**, the compliant structure **744'** is similar to the compliant structure on the ferrule **12** shown in FIG. **3**, with the exceptions that the frame insert **712'** is a one-piece structure and is provided with fiber grooves on surfaces at the perimeter of the ferrule insert **712'** in this embodiment. The resultant compliant structure **744'** resembles a C-shaped structure, having a slit opening **770**. Similar design considerations and objectives are applicable to the present embodiment. This embodiment provides essentially a 3-point contact on the alignment pin within the opening **799** (two beveled surfaces and the inside surface of finer **742'**.

In FIG. **27**, the compliant structure **744"** resembles the structure shown in FIG. **25**, with the exceptions that V-grooves **760** are provided instead of the circular grooves in the FIG. **25**, and a small slot **795** is provided in line with the slit **770** which facilitates flexing of the fingers **742"**. This embodiment provides a 4-point contact within the opening **797**.

In another embodiment, a ferrule frame surrounds the perimeter of the ferrule insert. FIGS. **28**-**32** illustrate a high density optical fiber connector in accordance with a further embodiment of the present invention. In this embodiment, the optical fiber connector **810** includes a single piece ferrule **812**, a frame **852**, a ferrule housing and a cable boot (similar to those shown in FIG. **2** but are omitted from view for simplicity). In this embodiment, the ferrule **812** is configured to align the terminating optical fibers (**20***a*, **20***b*) of ribbon cables (**22***a*, **22***b*) in two rows in two parallel planes. The optical fibers **20***a* and **20***b* alternately extend from the different optical fiber cables **22***a* and **22***b*. As illustrated in FIG. **30**, the terminating optical fibers **20***a* of the first fiber cable **22***a* are supported on grooves **824***a* provided on the top surface at the perimeter of the ferrule **812**, and the terminating optical fibers **20***b* of the second fiber cable **22***b* are supported on grooves **824***b* provided on the bottom surface at the perimeter of the ferrule **812**. The grooves (**824***a*, **824***b*) can take the same structure as grooves **24** on the surfaces of ferrule halves **12***b* in the embodiment of FIG. **3**, or the grooves in the embodiments of FIG. **5**.

Each groove (**824***a*, **824***b*) completely receives the corresponding optical fiber (**20***a*, **20***b*). The frame **852** has inside flat sections (**850***a*, **850***b*) facing the grooves (**824***a*, **824***b*) when the ferrule **812** is inserted into the frame **852**. The flat sections (**850***a*, **850***b*) completely cover the grooves (**824***a*, **824***b*). Given that the optical fibers (**20***a*, **20***b*) are completely retained in the grooves (**824***a*, **824***b*), the optical fibers (**20***a*, **20***b*) are positioned with precision in the ferrule halves (**12***a*, **12***b*) by the grooves (**824***a*, **824***b*). The position and orientation of the optical fibers (**20***a*, **20***b*) is set by the location and parallelism of the grooves (**824***a*, **824***b*). Accordingly, the relative locations (e.g., spacing) of the optical fibers (**20***a*, **20***b*) in the ferrule halves (**12***a*, **12***b*) are precisely maintained within the ferrule, e.g., for alignment to fibers in an opposing optical fiber connector (which has a female structure to receive the alignment pins **18**). No complementary ferrule or frame would be required to securely and precisely position the fibers within the optical fiber connector **810**. Even though the frame **852** does not serve any alignment function or effective support to accurately position the fibers (**20***a*, **20***b*) in the ferrule **812**, however, the frame **852** serves to cover the grooves (**824***a*, **824***b*) to prevent accidental dislodgment of the optical fibers.

The jackets (**27***a*, **27***b*) of the fiber cables (**22***a*, **22***b*) are inserted through openings in the strain relief anchor **856**, and are supported on the extension **858**. The extension **858** has a stub **860** extending into a central opening **862** in the ferrule **812**. Alignment pins **18** are inserted into holes **864** provided in the ferrule **812**, extending into holes **866** provided in the strain relief anchor **856**. The holes **864** are defined by a split **868** provided at each edge of the ferrule **812**. The thickness of the material of at least one prong **870** defining the split is made thinner, to facilitate flexing of the prong **870**. A flexure is thus formed, which defines a compliant structure that clamps the alignment pins to accurately and precisely locate the alignment pins for alignment to another complementary optical fiber connector.

While the frame **852** is shown to surround the perimeter of the ferrule **812** in the illustrated embodiment, a frame may be structured to cover the grooves (**824***a*, **824***b*) without surrounding the perimeter of the ferrule **812**. For example, a frame may be structured to be a partial ring (e.g., C-shaped) in the end view of FIG. **30** instead of a complete ring (not shown). Alternatively, the frame **852** may be omitted, and the anchor **856** may be provided with two extending flat fingers covering the grooves (**824***a*, **824***b*) on the top and bottom surface of the ferrule **812** (not shown).

As were in the case of the previous embodiments, the ferrule **812**, frame **852** and/or the anchor **856** may be made of metal and formed by high-throughput stamping and/or extrusion processes.

The high density ferrule structure is the subject matter of a separate U.S. patent application concurrently filed herewith (U.S. patent application Ser. No. 13/650,099). Such application is incorporated by reference as if fully set forth herein.

For the above described embodiments, the ferrules may be made of a metal material, which may be chosen to have high stiffness (e.g., stainless steel), chemical inertness (e.g., titanium), high temperature stability (nickel alloy), low thermal expansion (e.g., Invar), or to match thermal expansion to other materials (e.g., Kovar for matching glass). In another aspect of the present invention, the inventive ferrules are precision formed by high throughput processes, such as stamping and extrusion.

The ferrule in accordance with the present invention overcomes many of the deficiencies of the prior art. The compliant clamping structure makes it possible for the alignment pins to be inserted into the holes with no clearance, thus not requiring epoxy to fill any clearance between the holes and the alignment pins. By not having any clearance between the grooves in the ferrule and the fibers and alignment pins which would otherwise lead to movements between the parts, the alignment pins and the fibers can be more accurately located relative to each other. The spacing of the fibers and pins can be better maintained under changes in environmental conditions, for example, as the ferrule can accommodate more dimensional variations without affecting specified alignment tolerances. The optical fiber connector thus formed results in low insertion loss and low return loss. The ferrule configuration also allows ease of attaching terminating fiber ends to the ferrules, compared to threading epoxy coated fibers through holes in prior art ferrules. Without using epoxy, the reliability of the optical fiber connector is not affected by any aging/creeping of epoxy material. By selecting appropriate materials for the ferrule, the performance of the optical fiber connector is less sensitive to thermal variations. The open structure of the ferrule lends itself to mass production processes such as stamping and extrusion, which are low cost, high throughput processes.

* * *

While the invention has been particularly shown and described with reference to the preferred embodiments, it will be understood by those skilled in the art that various changes in form and detail may be made without departing from the spirit, scope, and teaching of the invention. Accordingly, the disclosed invention is to be considered merely as illustrative and limited in scope only as specified in the appended claims.

We claim:

1. A ferrule for supporting an optical fiber in an optical fiber connector, comprising:

a body having a surface with at least an optical fiber groove defined thereon to support the optical fiber; and

a compliant structure defined in the body for clamping an alignment pin, wherein the compliant structure comprises a flexure defined by a slot defined in the body, wherein the slot extends in a direction towards the alignment pin at an angle to the surface of the body of the ferrule where the optical fiber groove is defined, wherein one end of the slot terminates with an opening at the surface of the body of the ferrule on which the optical fiber groove is also defined, and wherein surfaces adjacent each side of the opening of the slot directly contact the alignment pin under bias of the flexure.

2. The ferrule as in claim **1**, wherein the ferrule further comprises two opposing ferrule halves having opposing mating surfaces, wherein at least one of the ferrule halves comprises the body that has the optical fiber groove defined thereon to support the optical fiber.

3. The ferrule as in claim **2**, wherein the angle of the slot is perpendicular to the opposing mating surfaces.

4. The ferrule as in claim **2**, wherein the angle of the slot is not perpendicular to the opposing mating surfaces.

5. A ferrule for supporting an optical fiber in an optical fiber connector, comprising:

a ferrule insert having a surface with at least an optical fiber groove defined thereon to support the optical fiber; and

a ferrule frame having a body surrounding the ferrule insert and having a compliant structure defined in the body for clamping an alignment pin, wherein the compliant structure comprises a flexure defined by a slot defined in the body, wherein the slot extends in a direction towards the alignment pin at an angle to the surface of the ferrule insert defining the optical fiber groove, wherein one end of the slot terminates with an opening, and wherein surfaces adjacent each side of the opening of the slot directly contact the alignment pin under bias of the flexure without the alignment pin being received within the slot.

6. The ferrule as in claim **5**, wherein the ferrule insert comprises two opposing ferrule plates having opposing mating surfaces, wherein at least one of the ferrule plates has the optical fiber groove defined thereon to support the optical fiber.

7. The ferrule as in claim **5**, wherein the ferrule frame comprises a front frame section and a rear frame section, wherein the front frame section is attached to a front end of the ferrule insert and the rear frame section is attached to a rear end of the ferrule insert.

8. The ferrule as in claim **7**, wherein the front and rear frame sections each includes the compliant structure, and wherein the alignment pin is inserted into the compliant structures provided on the front and rear frame sections.

9. The ferrule as in claim **5**, wherein the ferrule frame has a single, unitary structure, by which the ferrule insert is supported.

10. The ferrule as in claim **5**, wherein the angle of the slot is perpendicular to the surface of the ferrule insert defining the optical fiber groove.

11. The ferrule as in claim **5**, wherein the angle of the slot is not perpendicular to the surface of the ferrule insert defining the optical fiber groove.

12. The ferrule as in claim **5**, wherein the compliant structure of the ferrule frame is precision formed by stamping a body of metal material.

13. The ferrule as in claim **6**, wherein the optical fiber groove in the ferrule insert is precision formed by stamping a body of metal material.

14. The ferrule as in claim **1**, wherein the compliant structure is precision formed by stamping a body of metal material.

15. The ferrule as in claim **14**, wherein the optical fiber groove is also precision formed by stamping the body of metal material.

16. The ferrule as in claim **1**, wherein the optical fiber groove is precision formed by stamping the body of metal material.

17. The ferrule as in claim **1**, wherein beveled surfaces are defined adjacent each side of the opening of the slot, wherein the beveled surfaces directly contact the alignment pin.

18. The ferrule as in claim **5**, wherein beveled surfaces are defined adjacent each side of the opening of the slot, wherein the beveled surfaces directly contact the alignment pin.

19. The ferrule as in claim **5**, wherein the ferrule insert is supported inside an opening provided in the ferrule frame.

20. The ferrule as in claim **19**, wherein the ferrule frame comprises a front frame section having a first opening and a rear frame section having second opening, wherein a front end of the ferrule insert is supported inside the first opening, and a rear end of the ferrule insert is supported inside the second opening, wherein the front and rear frame sections each includes the compliant structure, and wherein the alignment pin is inserted into the compliant structures provided on the front and rear frame sections.

* * * * *